“Trick or Treat”: Tevatron Status & Plans

Tevatron Collider Run II:
Status and Prospects

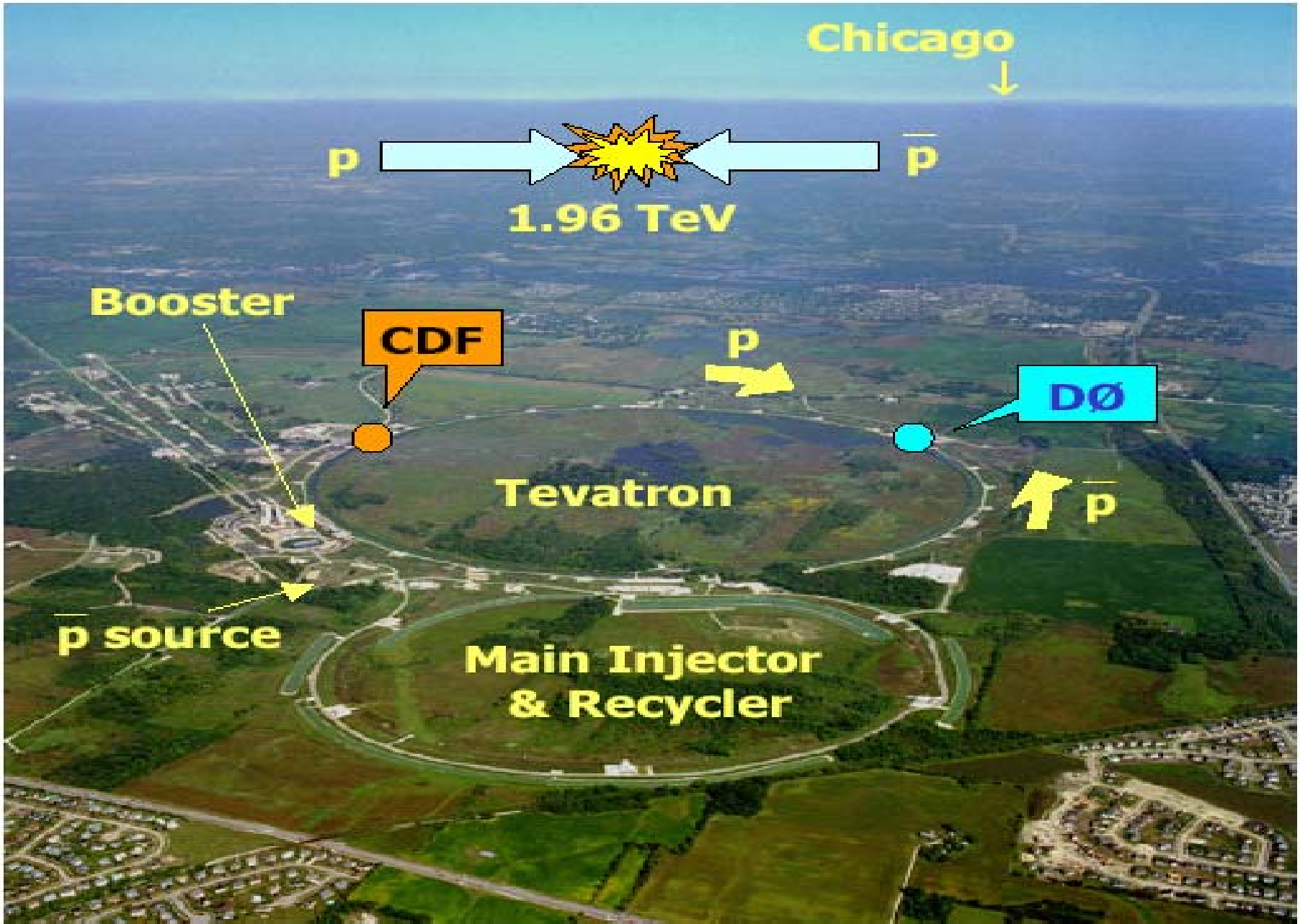
Vladimir Shiltsev
Fermilab

A Cinderella Story

..turning to..

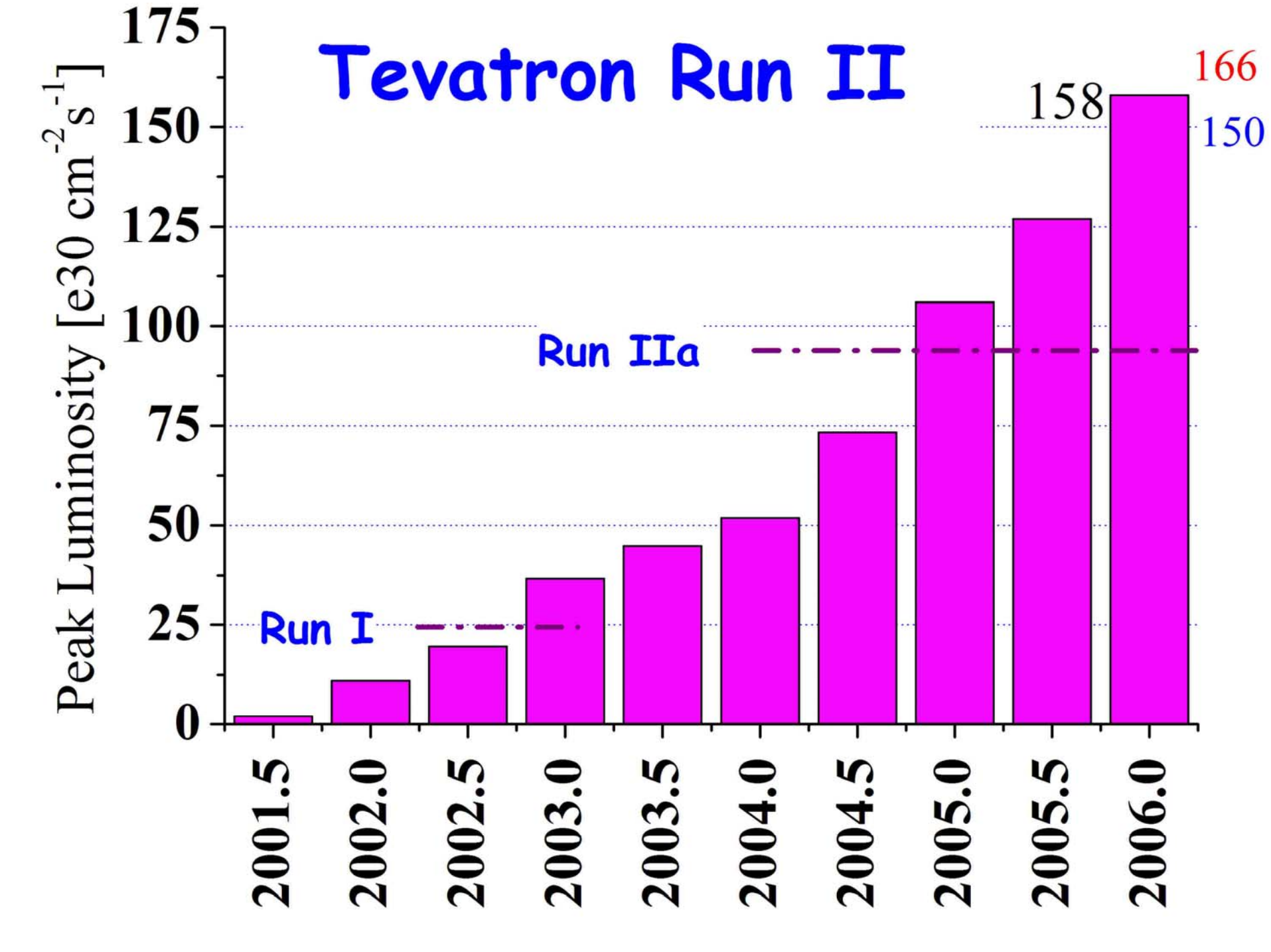
Madame Bovari

Tevatron Collider Run II

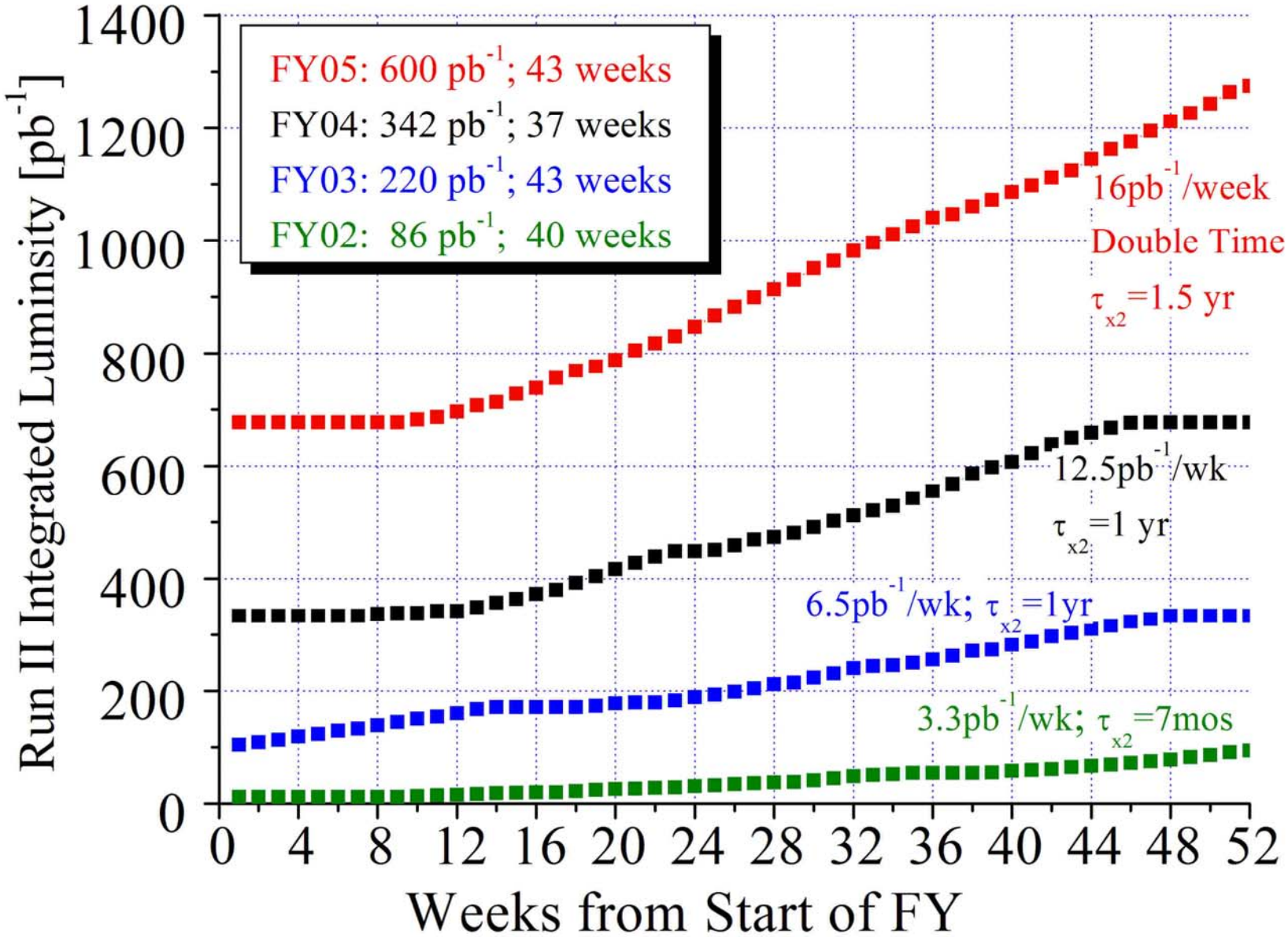


Introduction

- Tevatron Collider Run I:
  - 1992-1995, discovery of top-quark: "Top Turns Ten" Oct'05
  - Integral 150 pb-1, peak *L*=25e30 cm-1 s-1
  - 6(proton)x6(antiproton) bunches, 900 GeV/beam
- Original Run II Plan:
  - 2001-2007, Higgs and supersymmetry
  - 11-15 fb-1, peak *L*~86e30… with Recycler → 300-500
- Major Changes (1996-2000):
  - High intensity 150 GeV Main Injector
  - Antiproton Source Upgrade
  - 36x36 bunches in Tevatron, 980 GeV/beam
  - Recycler Ring with e-Cooling - for Run IIb


Tevatron Run II
Peak Luminosity [e30 cm^{-2}s^{-1}]
175
150
125
100
75
50
25
0
Run I
Run IIa
158
166
150
2001.5
2002.0
2002.5
2003.0
2003.5
2004.0
2004.5
2005.0
2005.5
2006.0

Luminosity Integral



Short History of Times

- 2001:
  - Mar: Run II begins
  - Dec: detectors "~ready" but L~10e30 cm-2 s-1 (40% of Run I)
- 2002:
  - May: AAC review, lot of concerns, L~20, "total mobilization", DoE calls other labs to help
  - July: L=26 – over Run I record
  - Oct: DoE Review "C-mark" , lower goals set for FY03, recycling & 140x140 abandoned,
- 2003:
  - Jan: Management changes, Luminosity Upgrade Project started
  - Mar: Integral>150 pb-1 (Run I), 1st CDF Run II paper published
  - July: DoE Review "C+", "…the next 6 months are critical"
  - Aug: L=50 (2xRunI)
  - Oct: FY03 integrated luminosity goal achieved, DoE mini-review
- 2004:
  - Feb: DoE Review -"B" mark
  - Jun: L>86 (Run IIa goal)
  - Sep: FY04 goal achieved, DoE mini-review
- 2005:
  - Feb: BTeV project cancelled; 2009 set as "the End"; DoE Review "B+"
  - June: 1 fb-1 celebrated
  - Aug: FY04 luminosity integral goal achieved
  - Oct: Record high for hadron colliders L=158e30 > SPS L=140e30 (1982)

Luminosity and Luminosity Integral

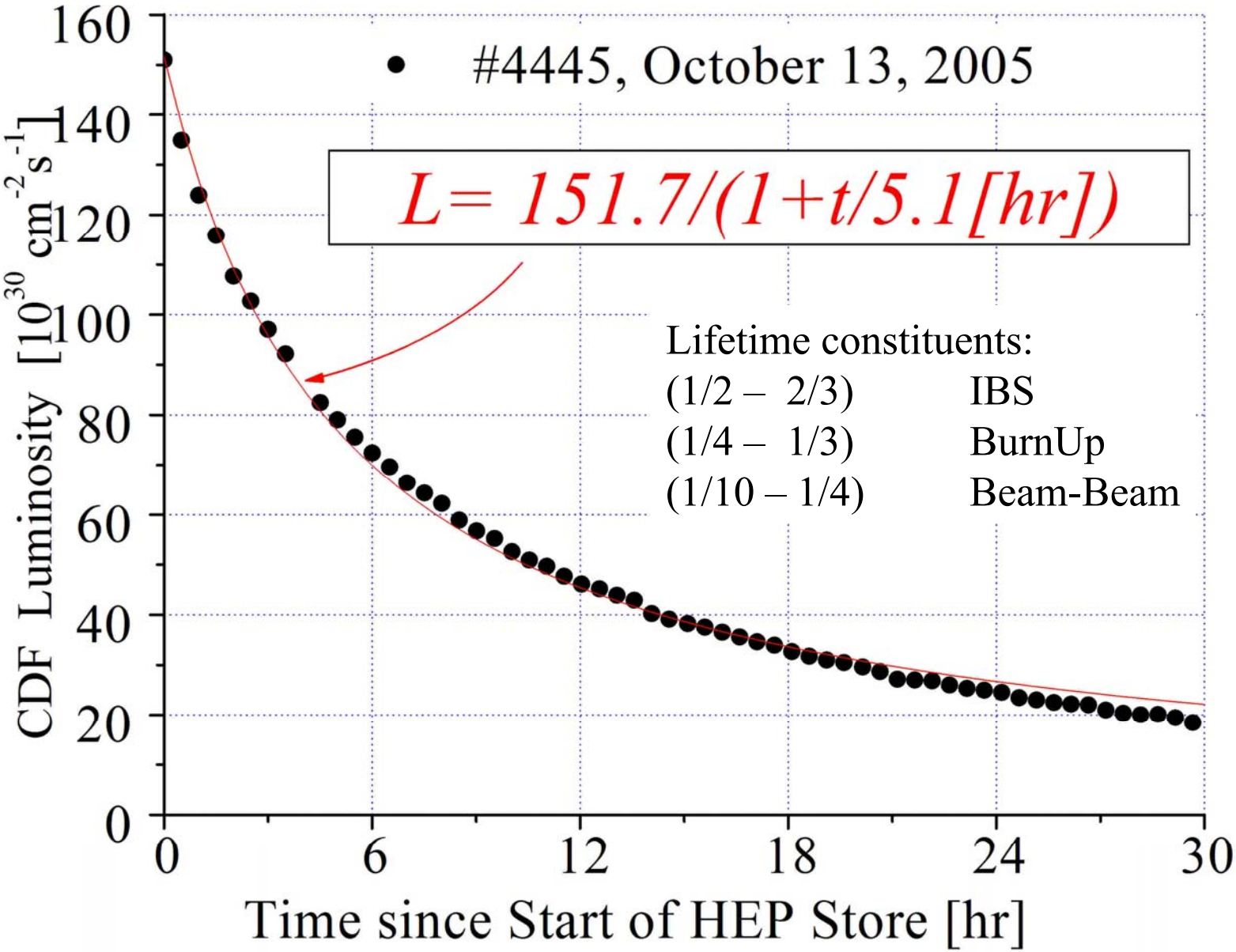
$$L = \frac{3\gamma \ f_0 \ B \ N_{\bar{p}} N_p}{\pi\beta^* \left(\varepsilon_p + \varepsilon_{\bar{p}}\right)} H\left(\sigma_l / \beta^*\right)$$

see slide

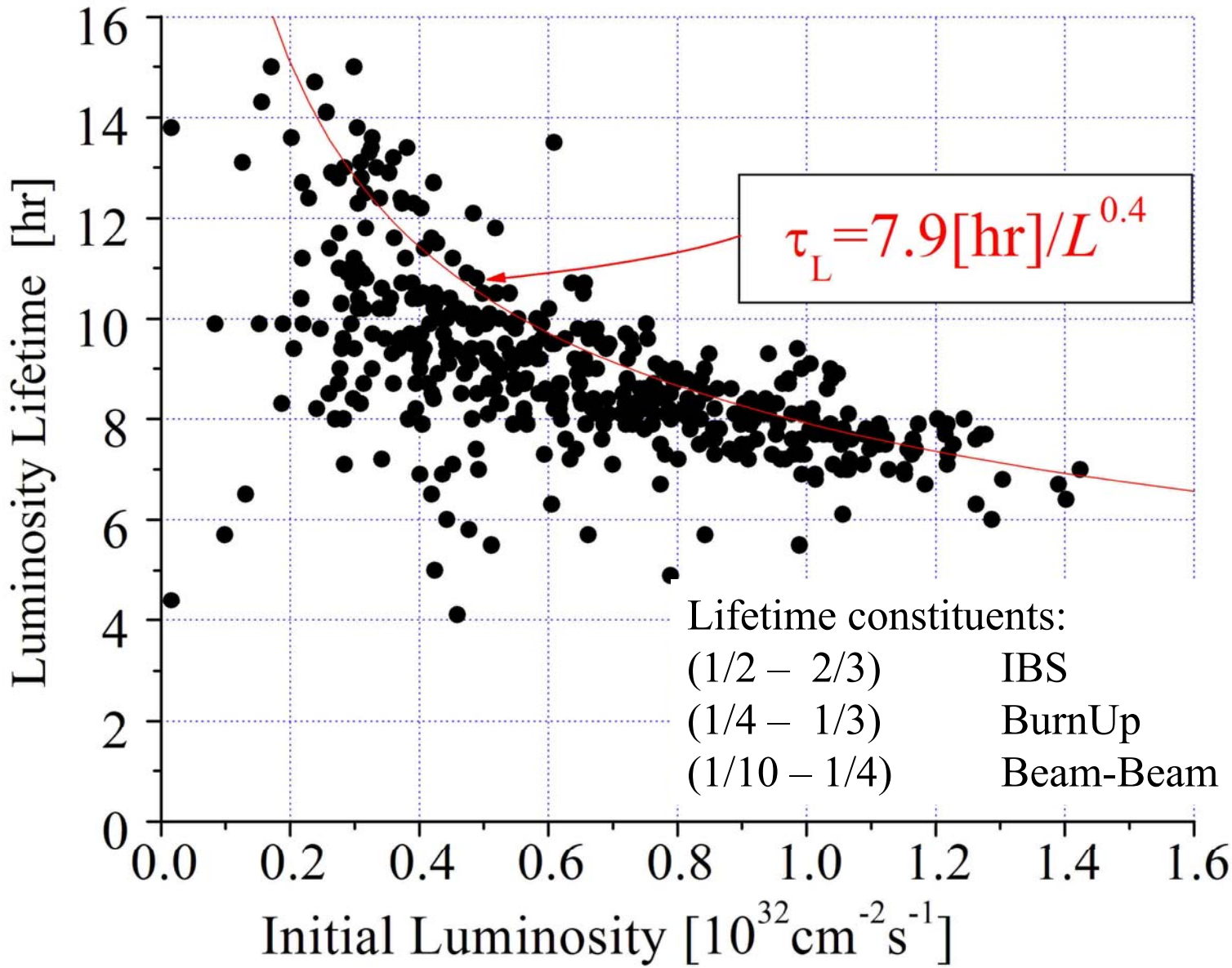
$$I = \int L dt = N_{stores} \tau_L L_0 \ln(1 + T / \tau_L)$$

- Luminosity Integral: primary factors
  - Beta* at IP and bunchlength: H(x)/beta^*
  - Emittances $\varepsilon_p \ \varepsilon_{pbar}$
  - Number of protons: N_p
  - Number of antiprotons: BN_{pbar}
  - Lumi-lifetime: τ_L
  - Number Stores: N_{stores}

Luminosity Decays as 1/(1+Time/τ)



Luminosity Lifetime vs Luminosity

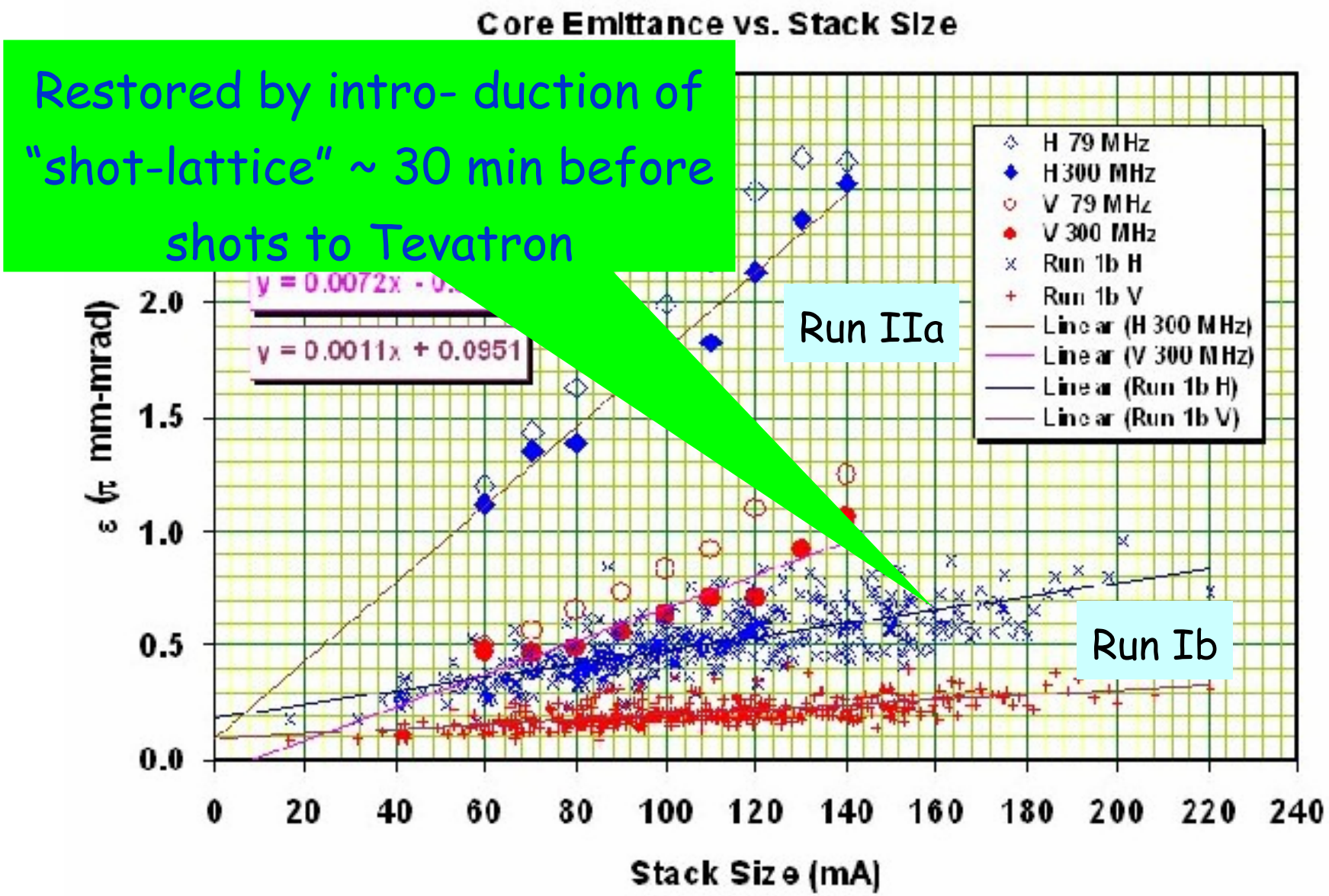


17 steps up in '02-05 → 1.17^{17} = 15 times

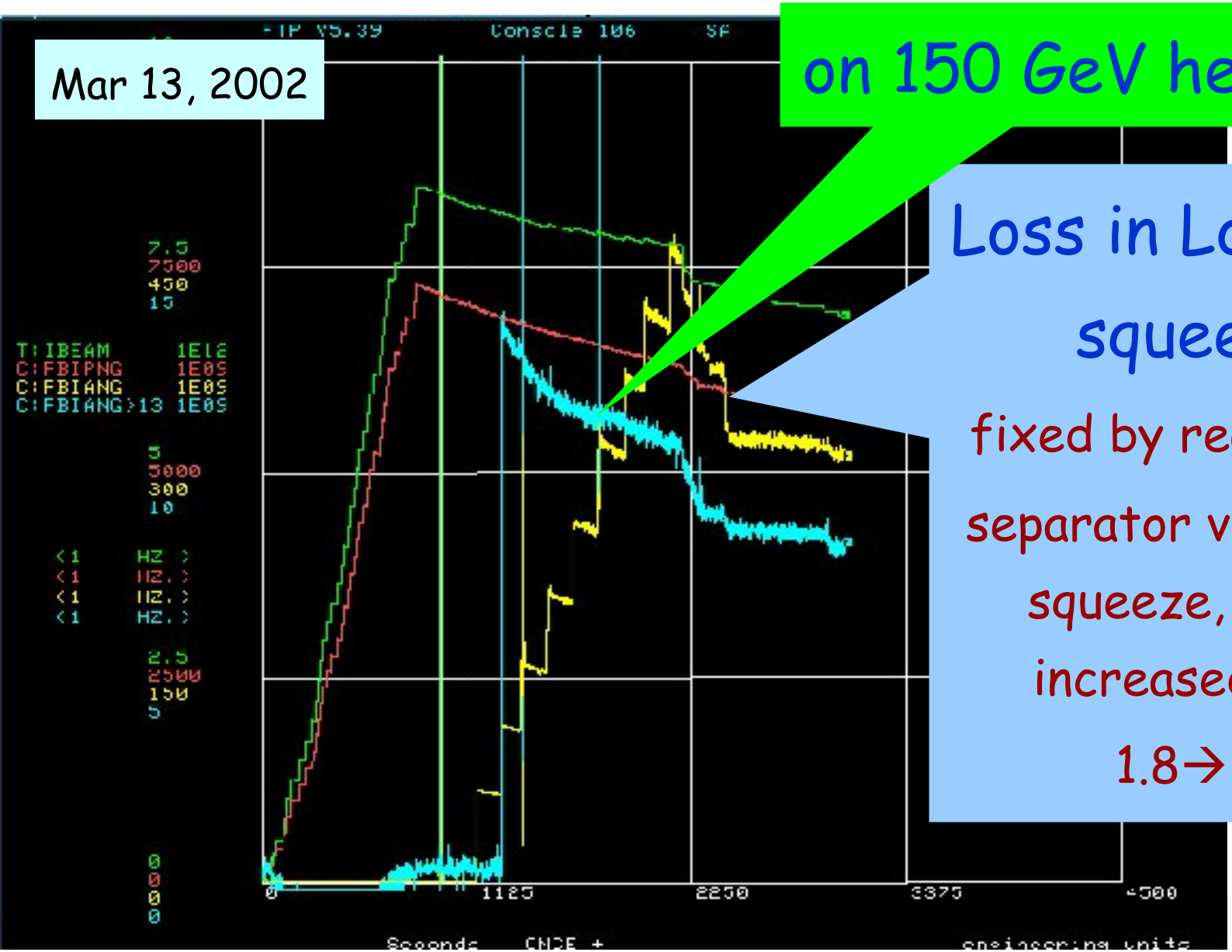
Integrated Lumi → $(15)^{0.6}$ =6 times

- AA Shot lattice vs IBS — July'02 — ~40 %
- Tev BLT/inst.dampers at injection — Sep'02 — ~10 %
- Pbar coalescing improved in MI — Oct'02 — ~5 %
- C0 Lambertsons Removed — Feb'03 — ~15 %
- S6 cuircuit tuned/SEMs removed — June'03 — ~10 %
- "5 star" helix on ramp — Aug'03 — ~2 %
- Reshimming/Alignment — Nov'03 — ~12 %
- Longer Stores/ MI dampers — Feb'04 — ~19 %
- 2.5MHz AA → MI trnsf/Cool shots — April'04 — ~8 %
- Reduction of beta* to 35 cm — May'04 — ~26 %
- Shots from Recycler — July'04 — ~20%
- Slip Stacking in MI — Mar'05 — ~20%
- Tev Octupoles at 150 GeV — April'05 — ~5%
- Reduction of beta* to 28 cm — Sep'05 — ~8 %

Emittance in AA: IBS Screwed Up

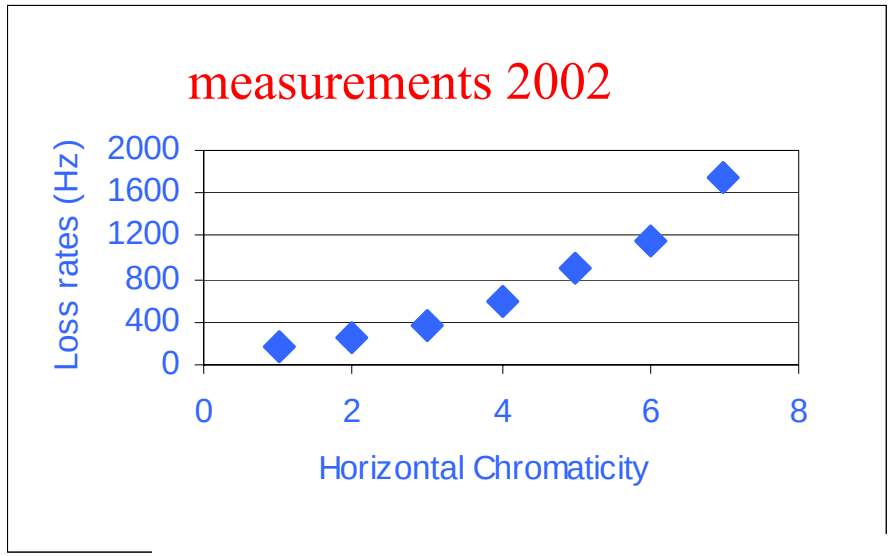


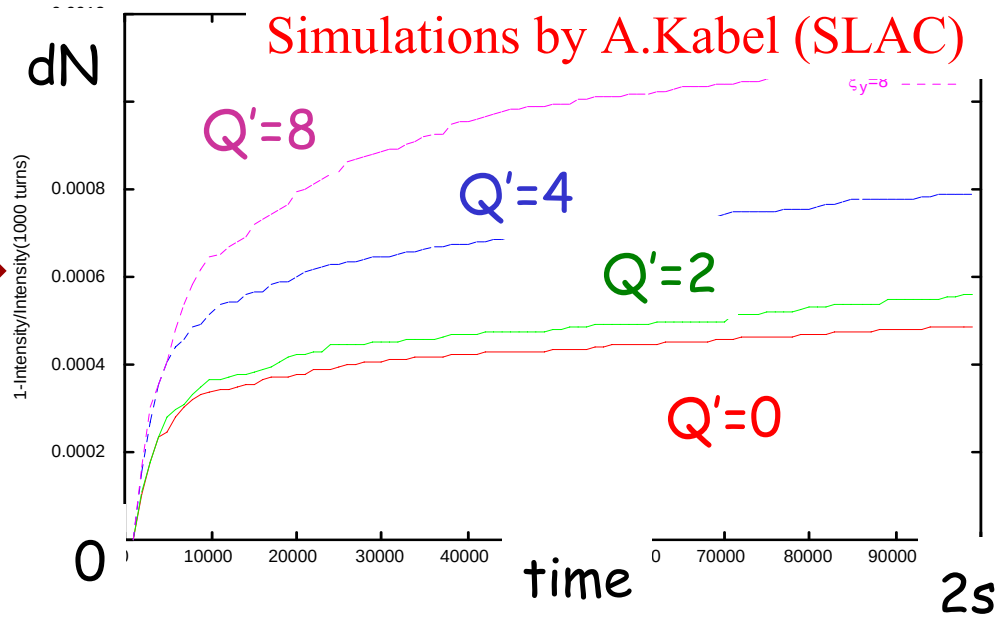
Beam-Beam Effects in Tevatron



Poor Pbar Lifetime on 150 GeV Helix

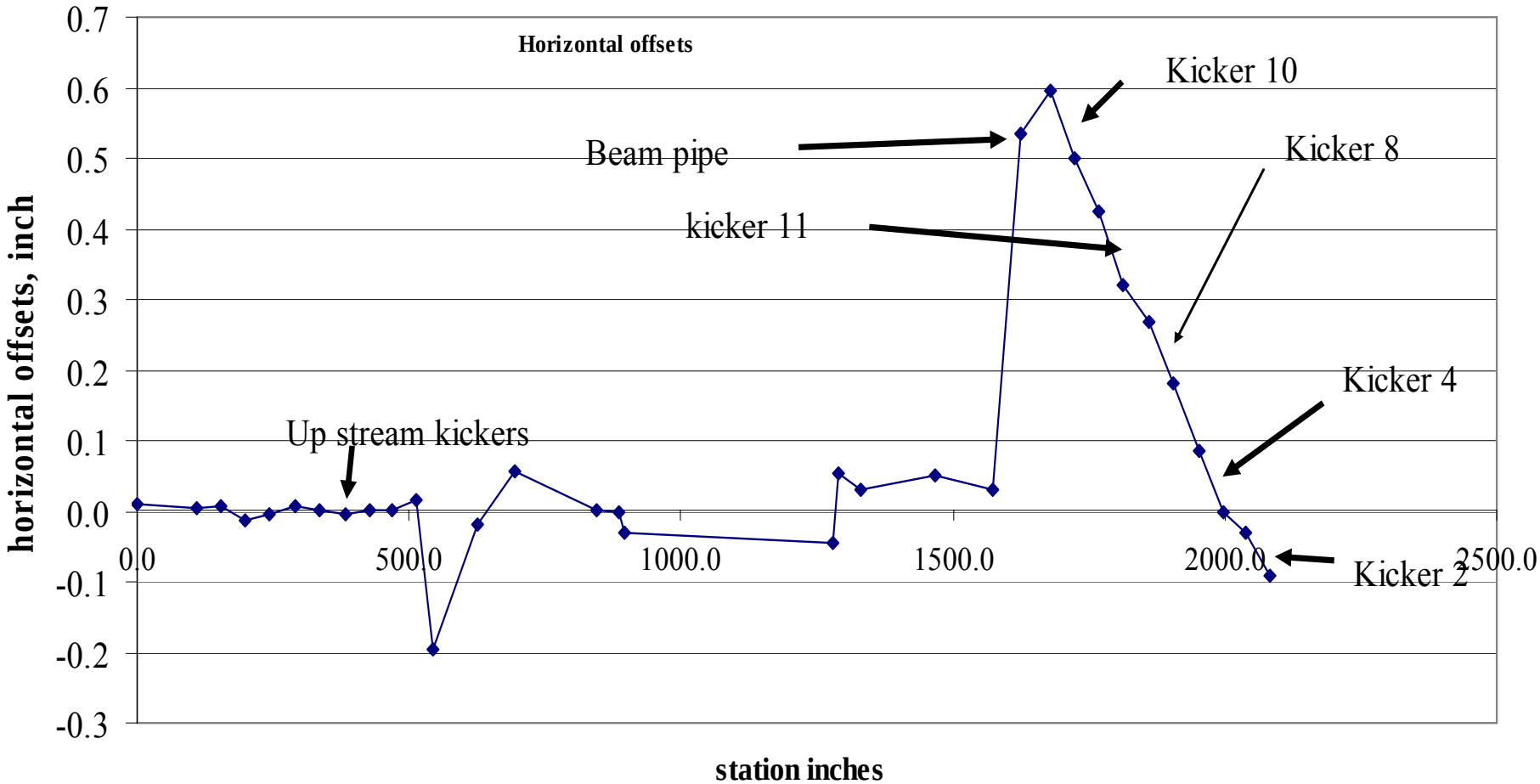
- Poor P/Pbar lifetime at 150
  - 1-4 hours, 15-20% loss
  - Sqrt(time) dependence
  - Worse with larger Np, Q'
  - Longitudinal shaving
- Possibilities to fix it:
  - Open aperture (C0, align)
  - Reduce emittances (reshimming)
  - Reduce impedance (F0 liner)
  - Reduce chromaticities
    - Found experimentally (plot)
    - Confirmed in simulations →
    - Weak HT Instability → liner, dampers, octupoles
    - **dN=15-20% → 2-4% !**





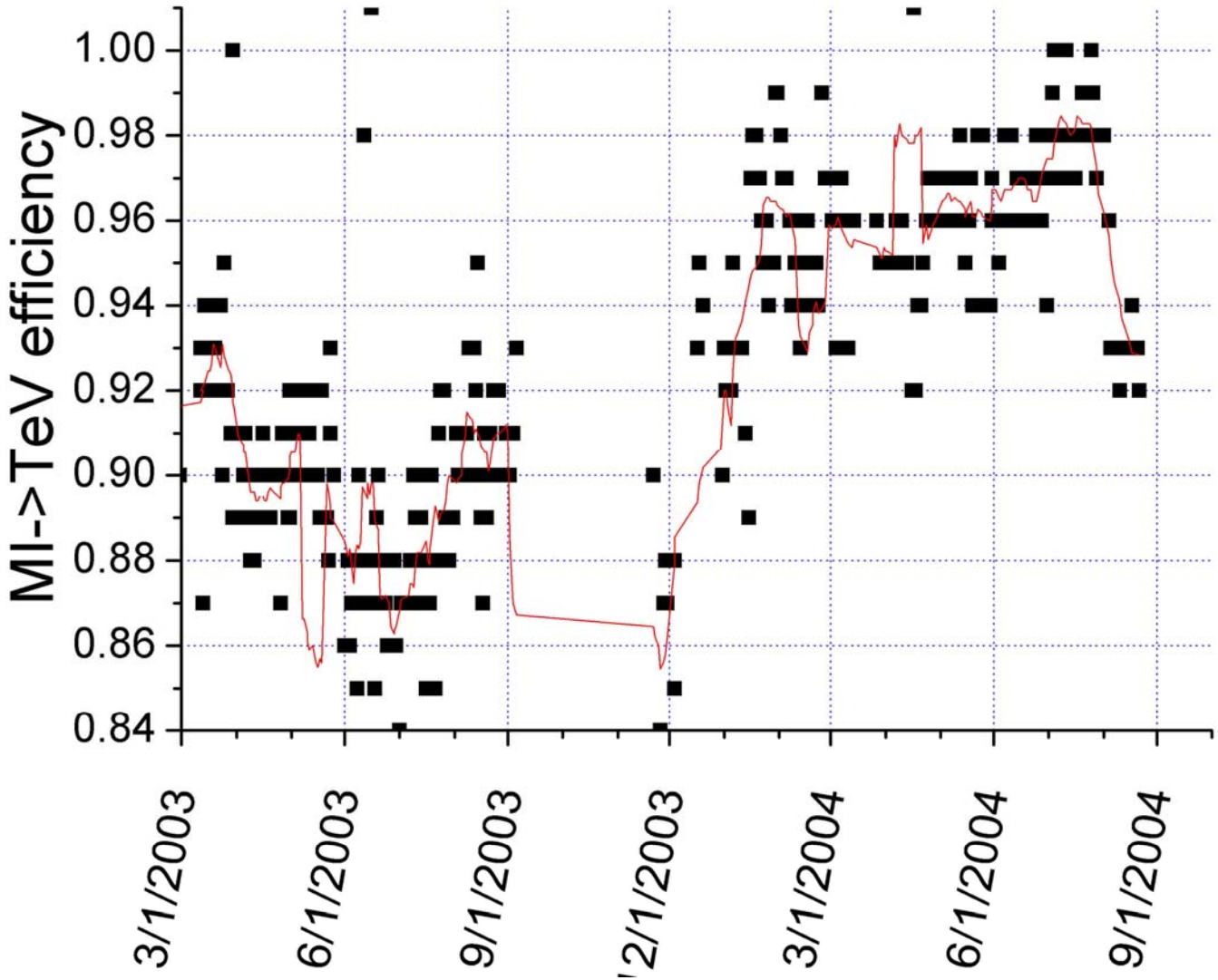
Tev Alignment: What it really means…

Misalignment → Fix → Open Apertures

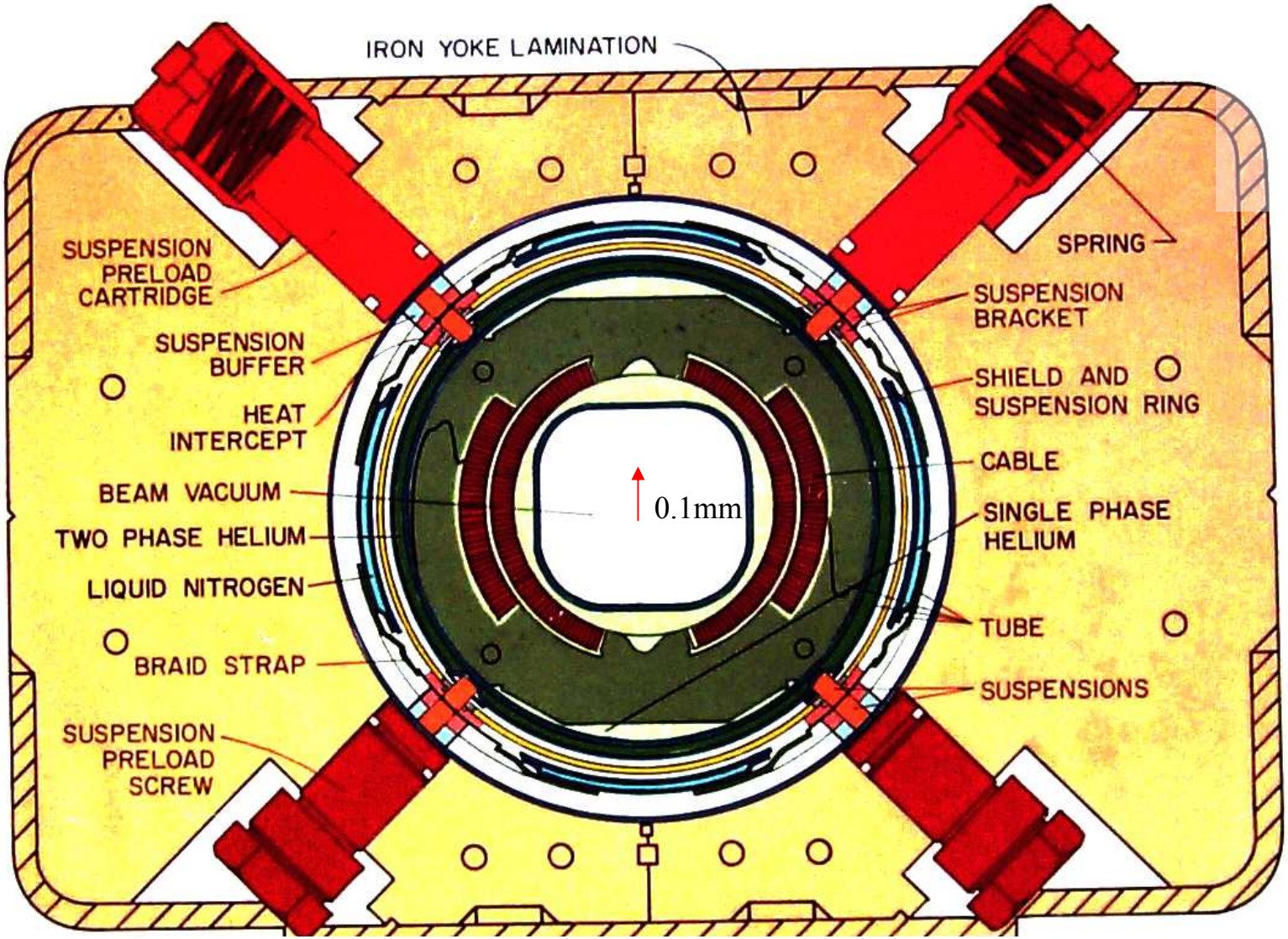


- Another ¼" misalignment fixed at D0
- Rolls >2mrad - completed
- # of dipole correctors running >35A out of 50A: 26 → 6

Alignment Pays Off in Transfer Efficiency



Reshimming=Lifting Up SC Coils

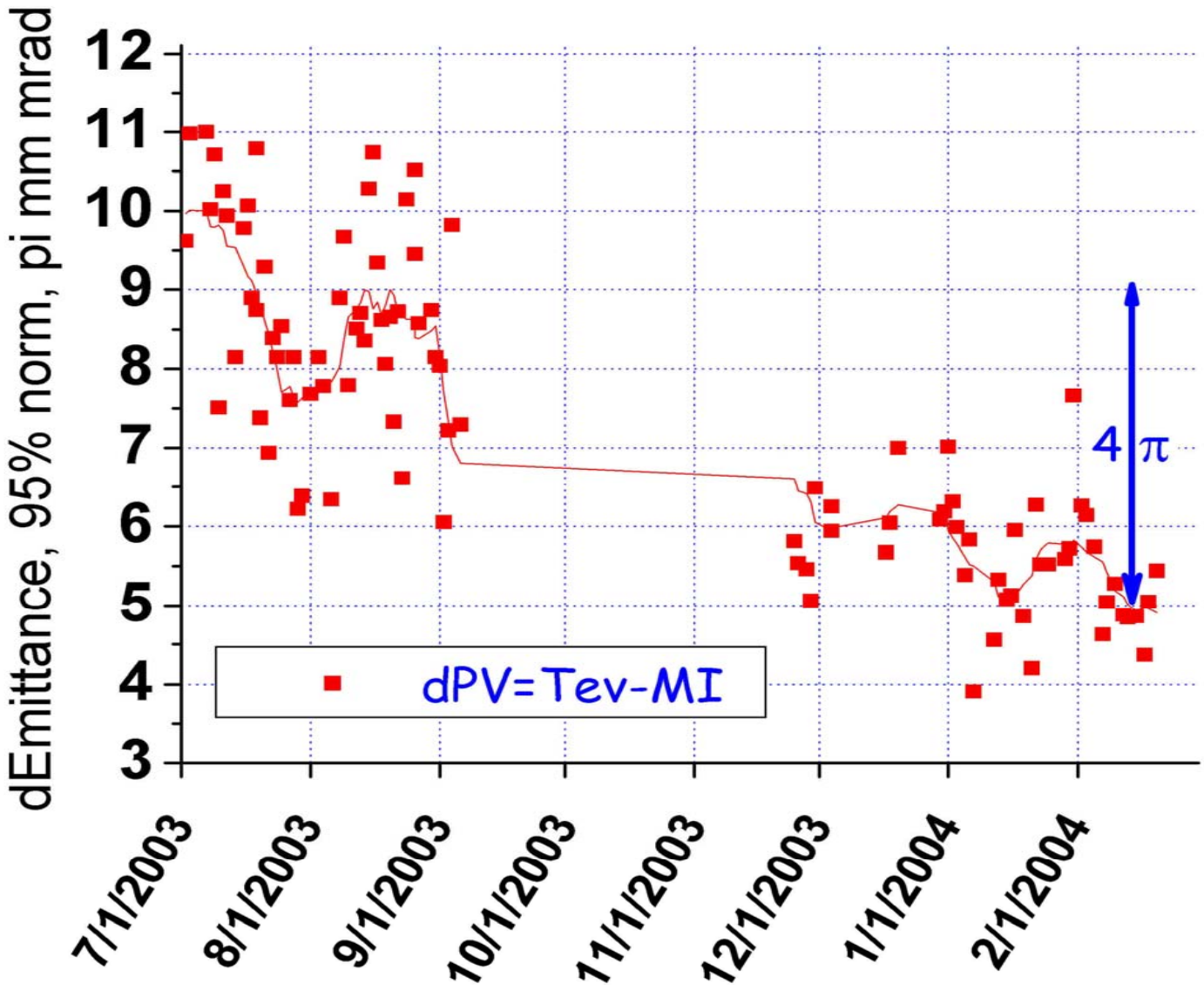


M.Syphers, D.Harding,TD team

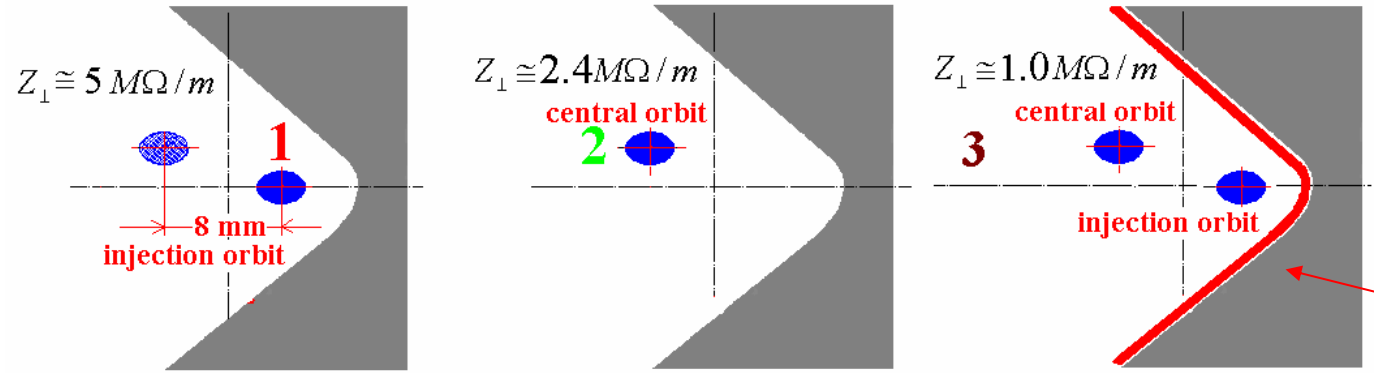
Reshimming of 108 most needed dipoles were supposed to reduce dε at inj in ‘03

As of now 604 out of 774 dipoles reshimmed (the rest in ’06)

Emittance Dilution in MI→Tev Transfer

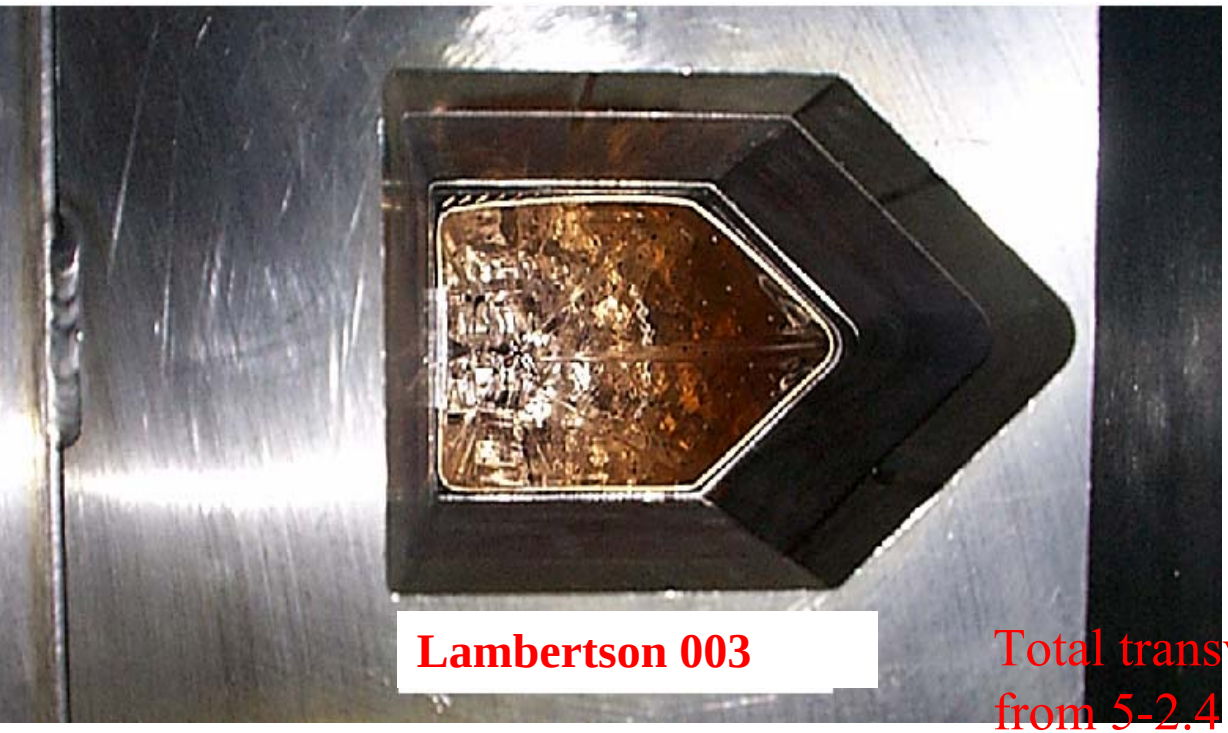


Tevatron Impedance

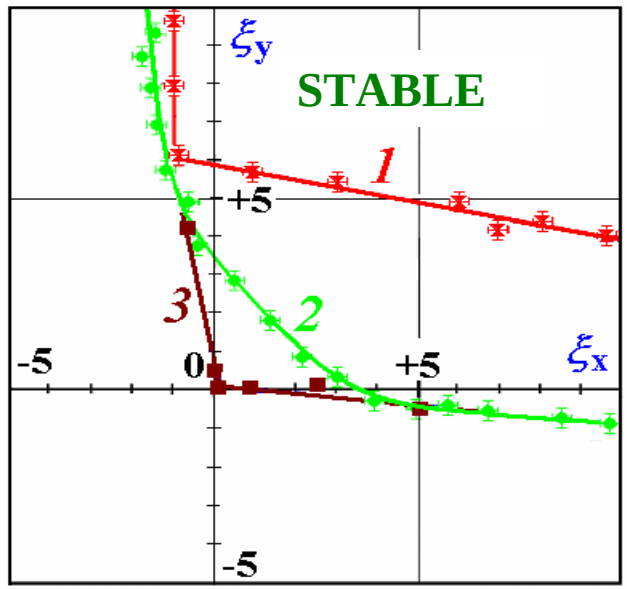


— P.Ivanov
A.Burov
A.Chen

0.4 mm liner
CuBe (98+2%)



Lambertson 003

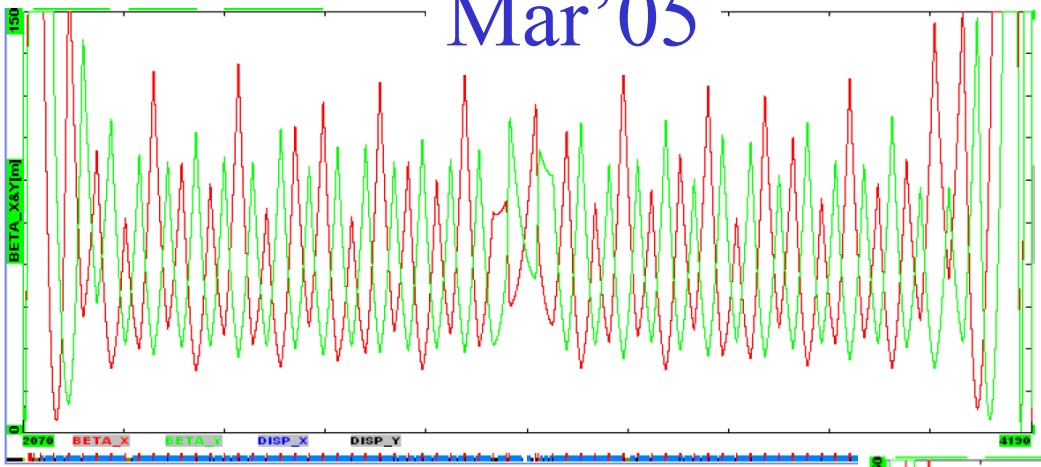


Total transverse impedance reduced from 5-2.4 MOhm/m to 1 MOhm/m

Octupoles to run at C_vh=0

β-functions : before & after

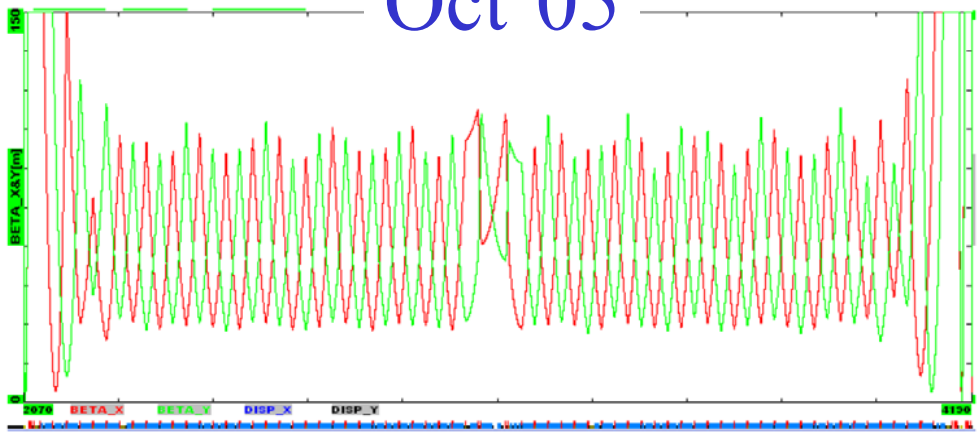
Mar'05



	β_x^* (cm)	β_y^* (cm)	
CDF	32.0	37.1	±5%
D0	35.8	40.0	±5%

A.Valishev
J.Annala
Yu.Alexahin
V.Lebedev

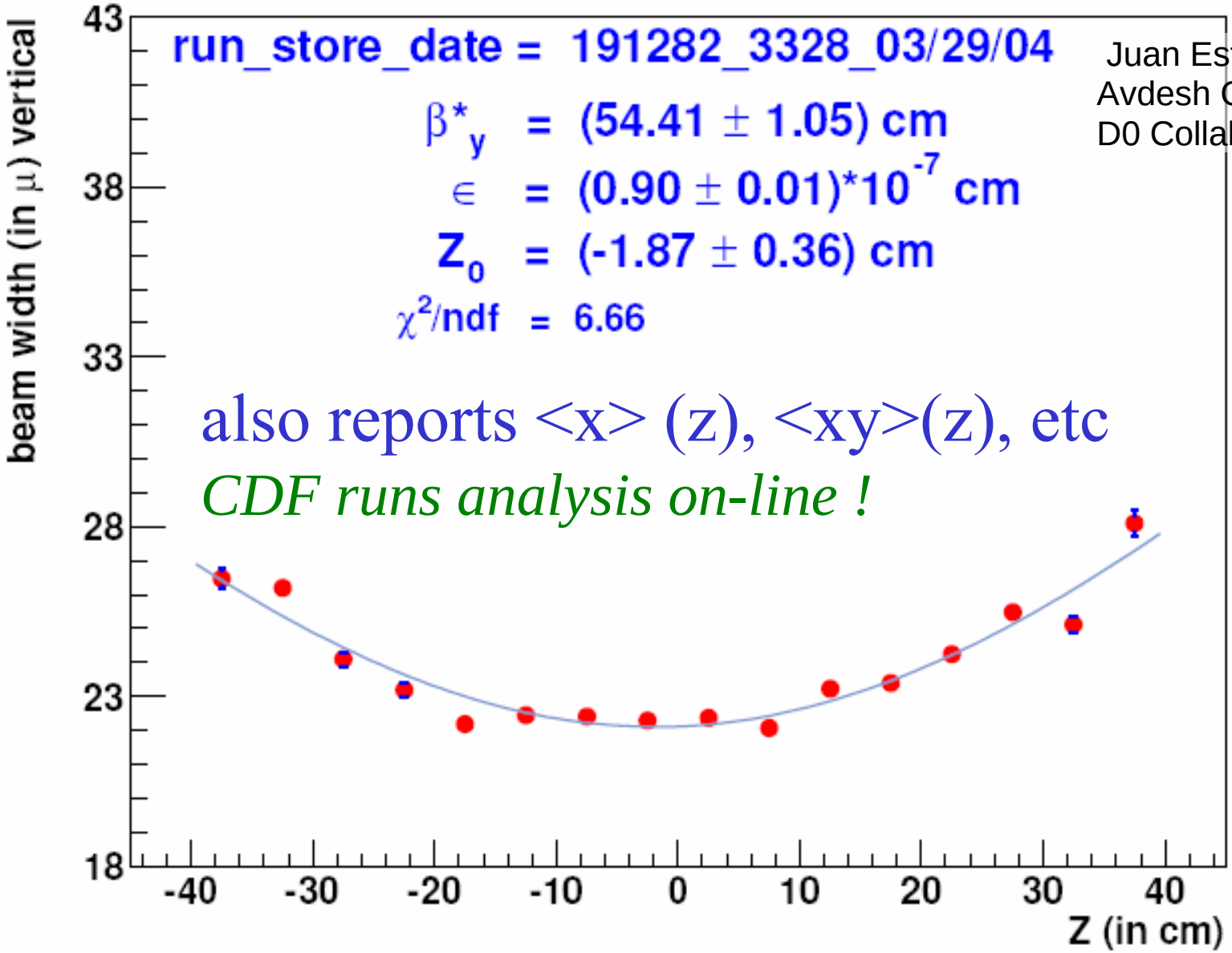
Oct'05



	β_x^* (cm)	β_y^* (cm)	
CDF	30.3	29.1	±5%
D0	29.2	28.2	±5%

Upgraded
Tevatron BPMs !

β* from Luminous Region Analysis

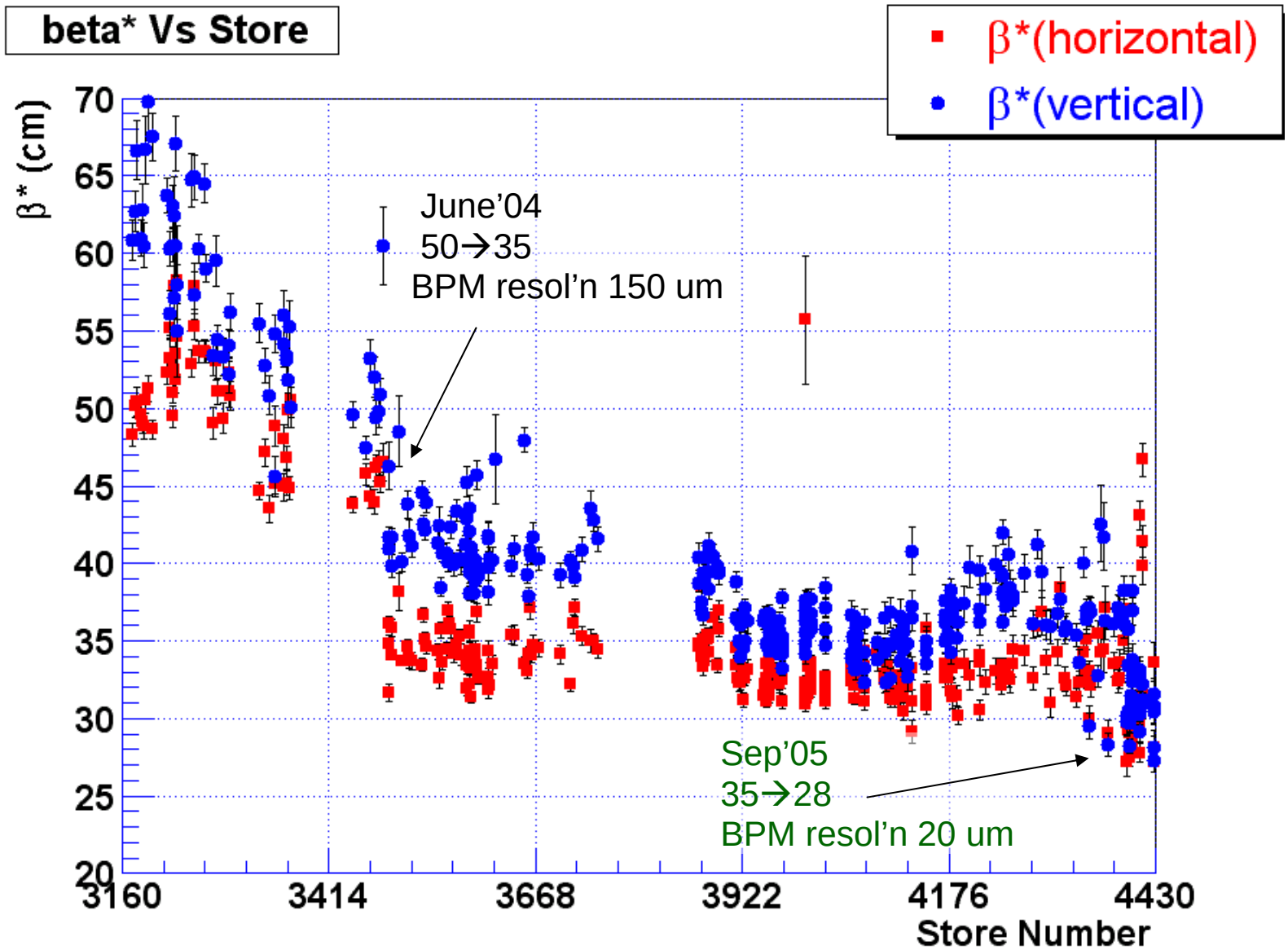


Juan Estrada,
Avdesh Chandra
D0 Collaboration

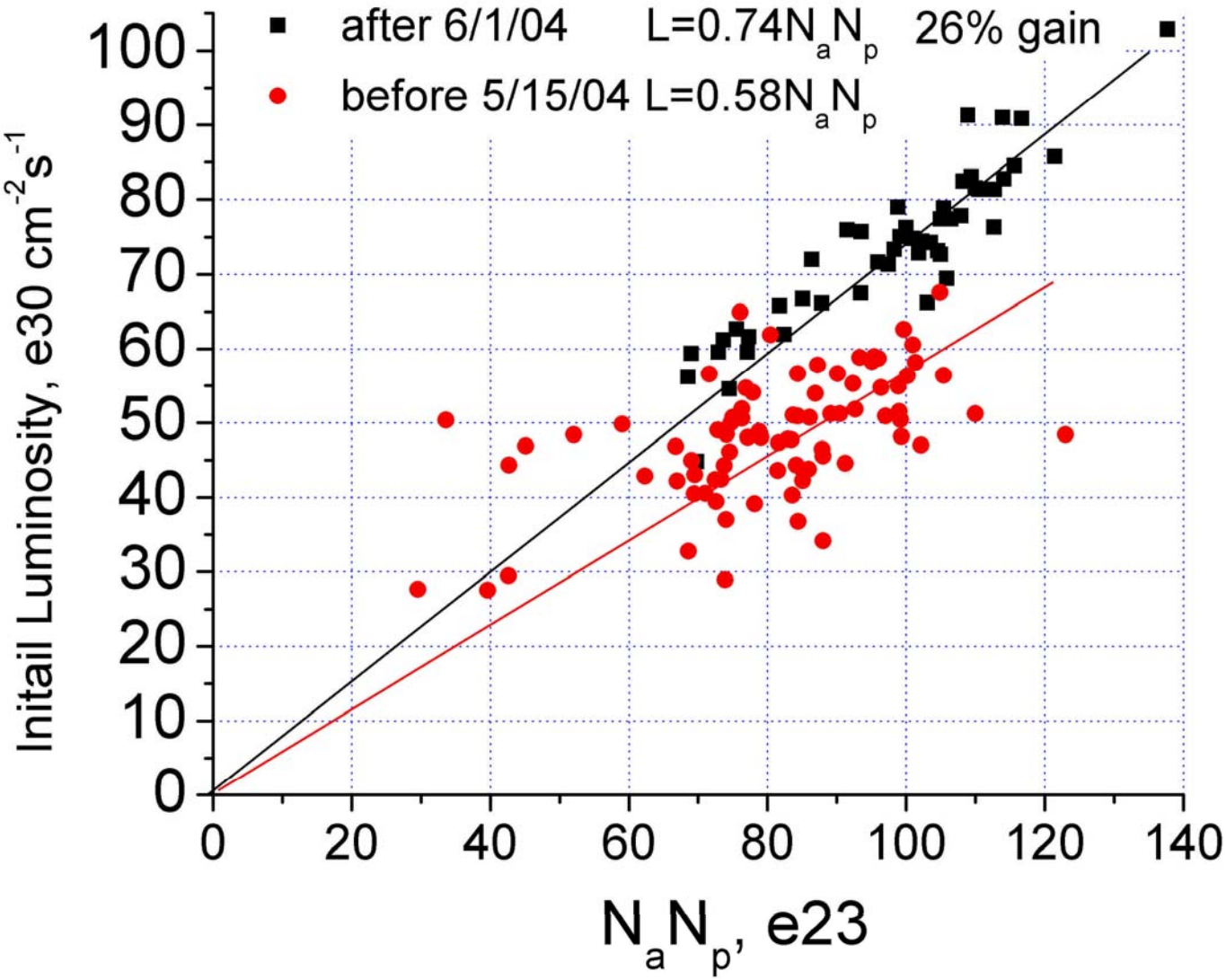
also reports <x> (z), <xy>(z), etc

CDF runs analysis on-line !

D0 Vertex Distribution Analysis



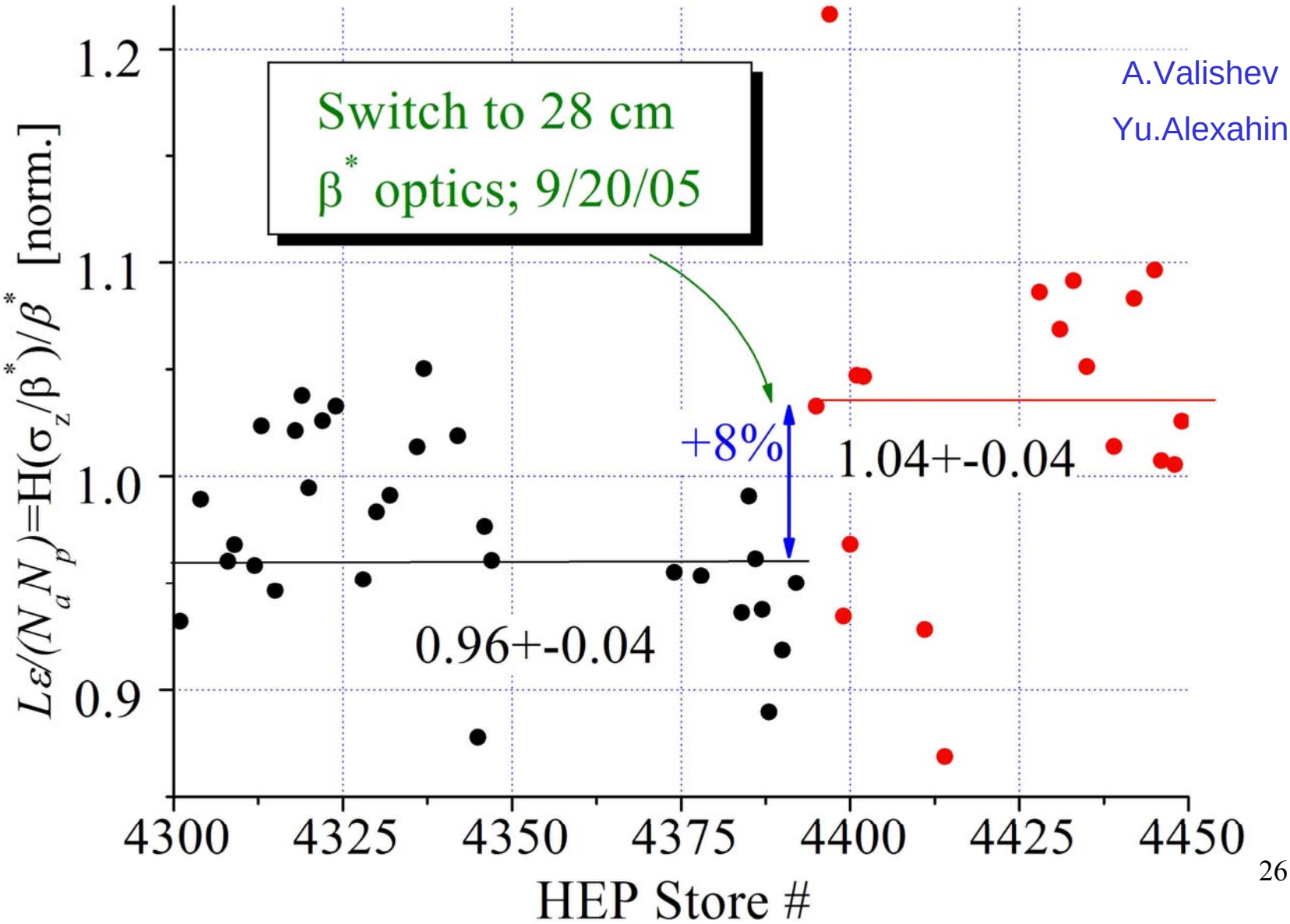
Jun'04: 26% Increase of Peak Luminosity



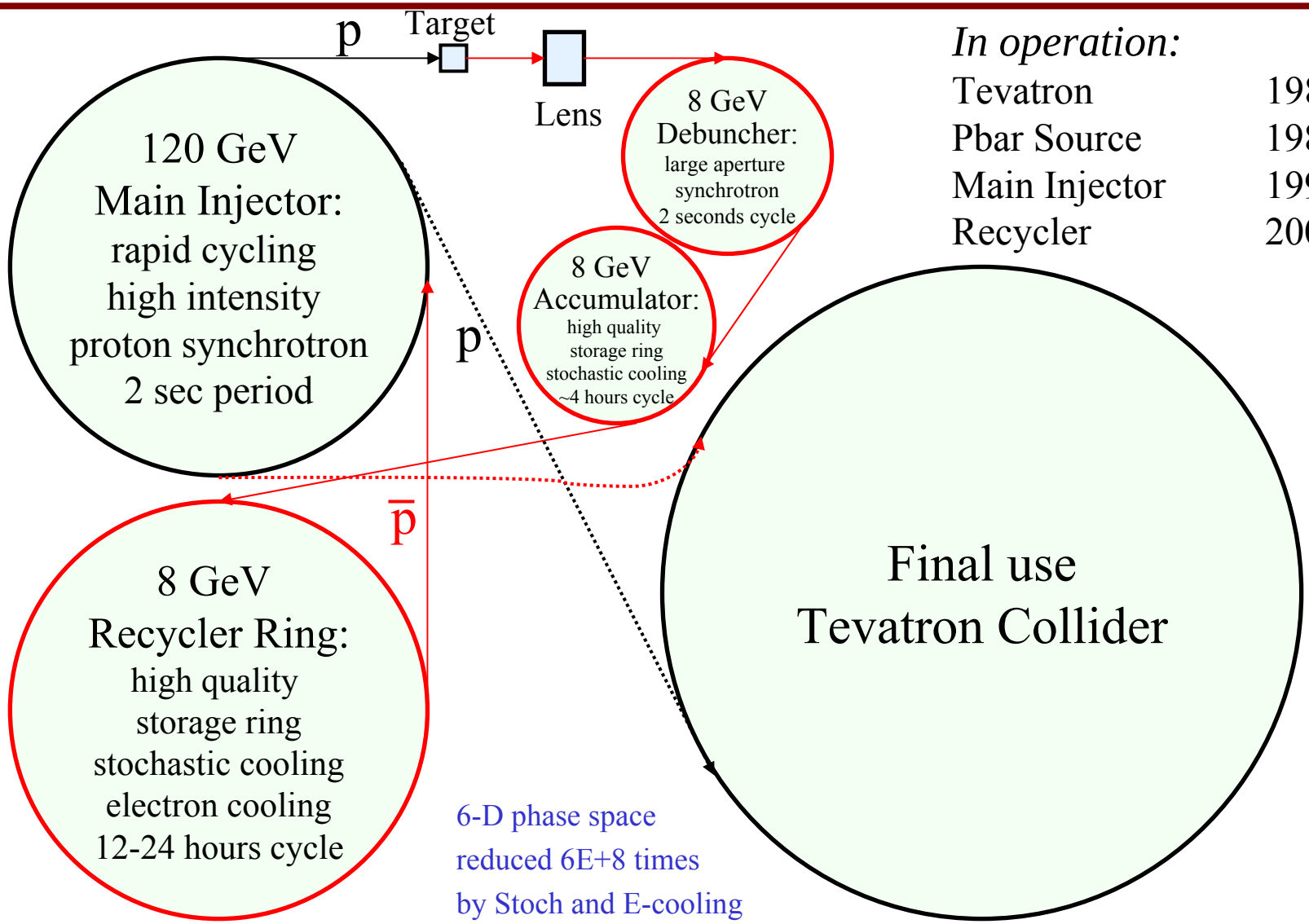
V.Lebedev

J.Annala

Sep'05 : Another Change: 35cm→28cm



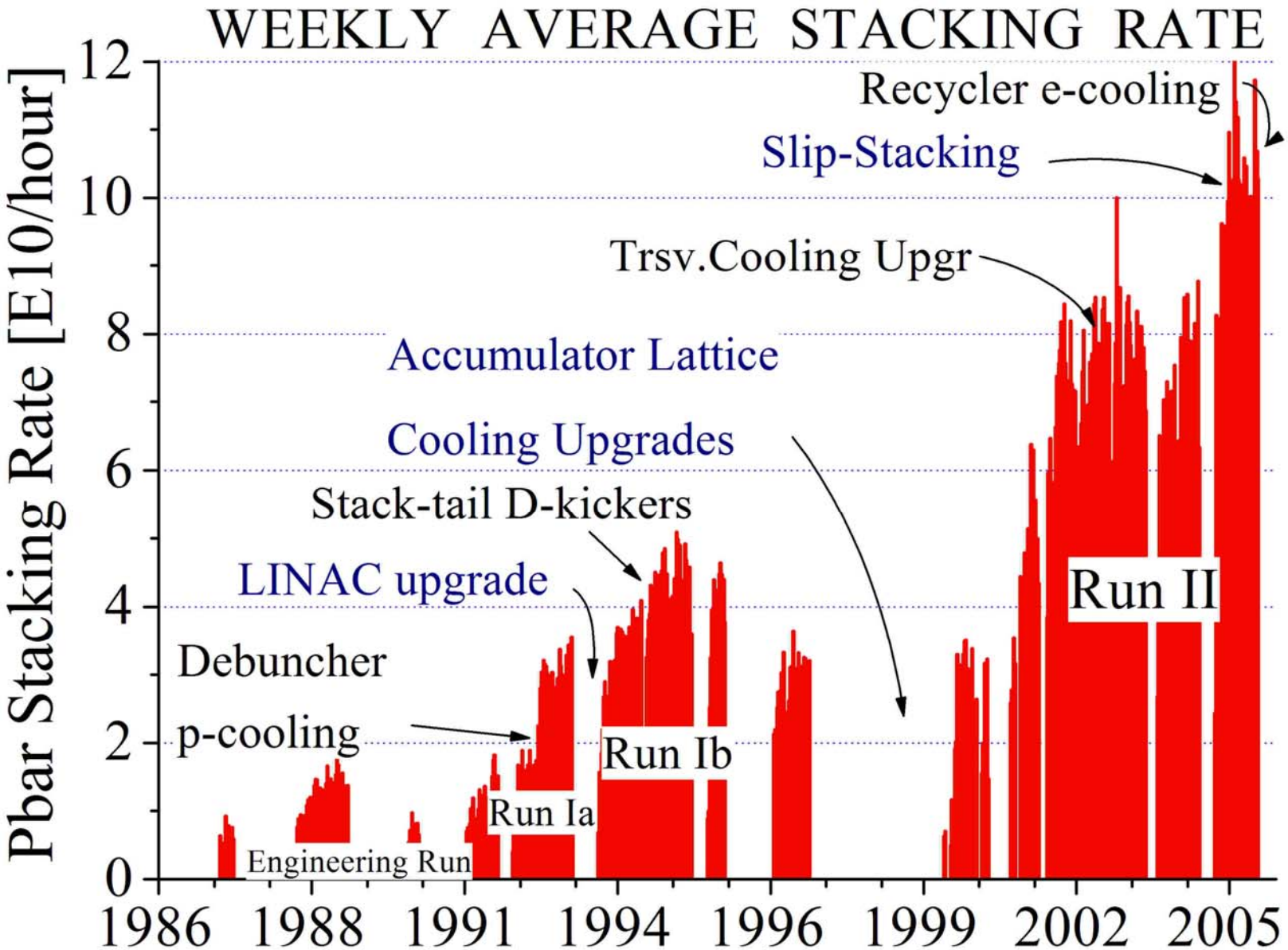
Antiproton Production Complex



In operation:

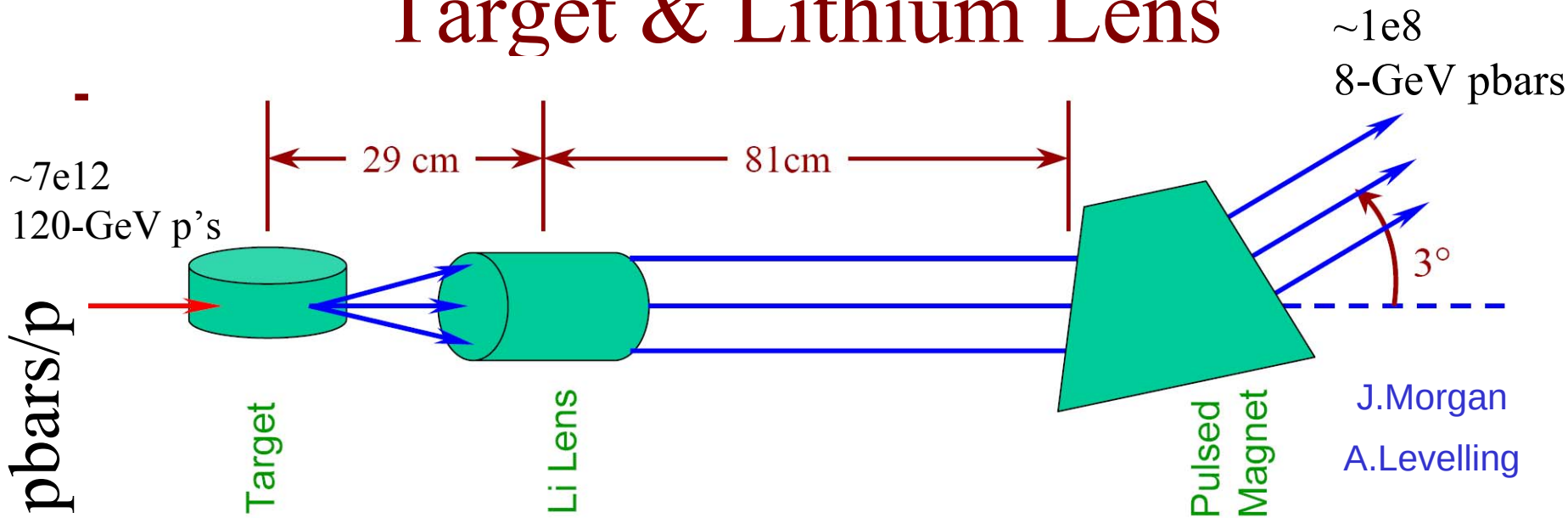
Tevatron	1983
Pbar Source	1985
Main Injector	1999
Recycler	2004

Antiproton Production at Fermilab

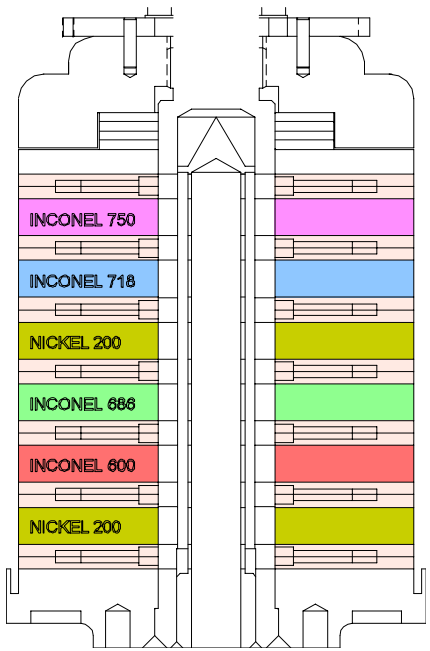


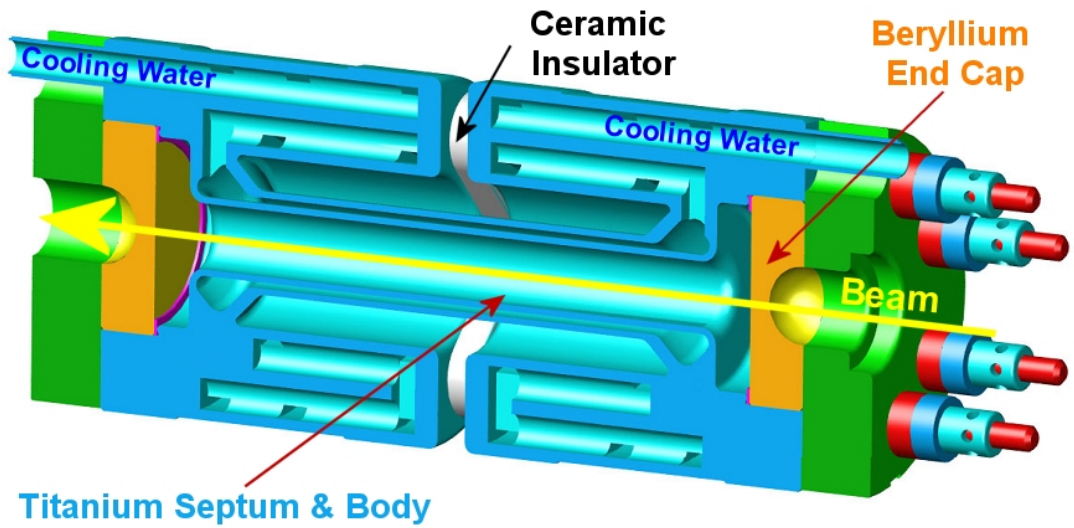
E.Harms

Target & Lithium Lens



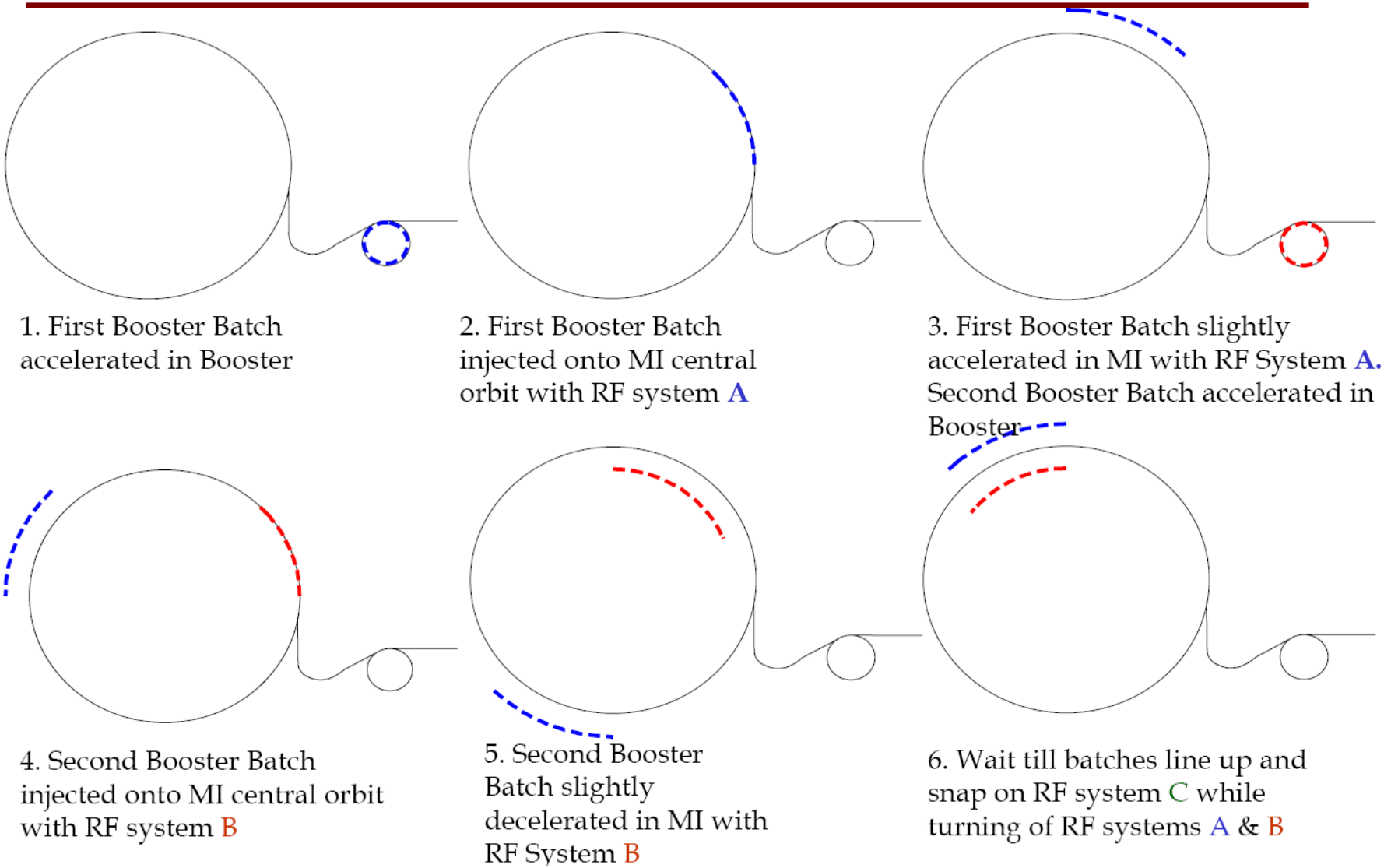
Yield ~1.8e-5 pbars/p





∅1cm; 10T/cm; 10M pulses (goal)

Slip Stacking: The Way to Double #p's on Target



1. First Booster Batch accelerated in Booster

2. First Booster Batch injected onto MI central orbit with RF system A

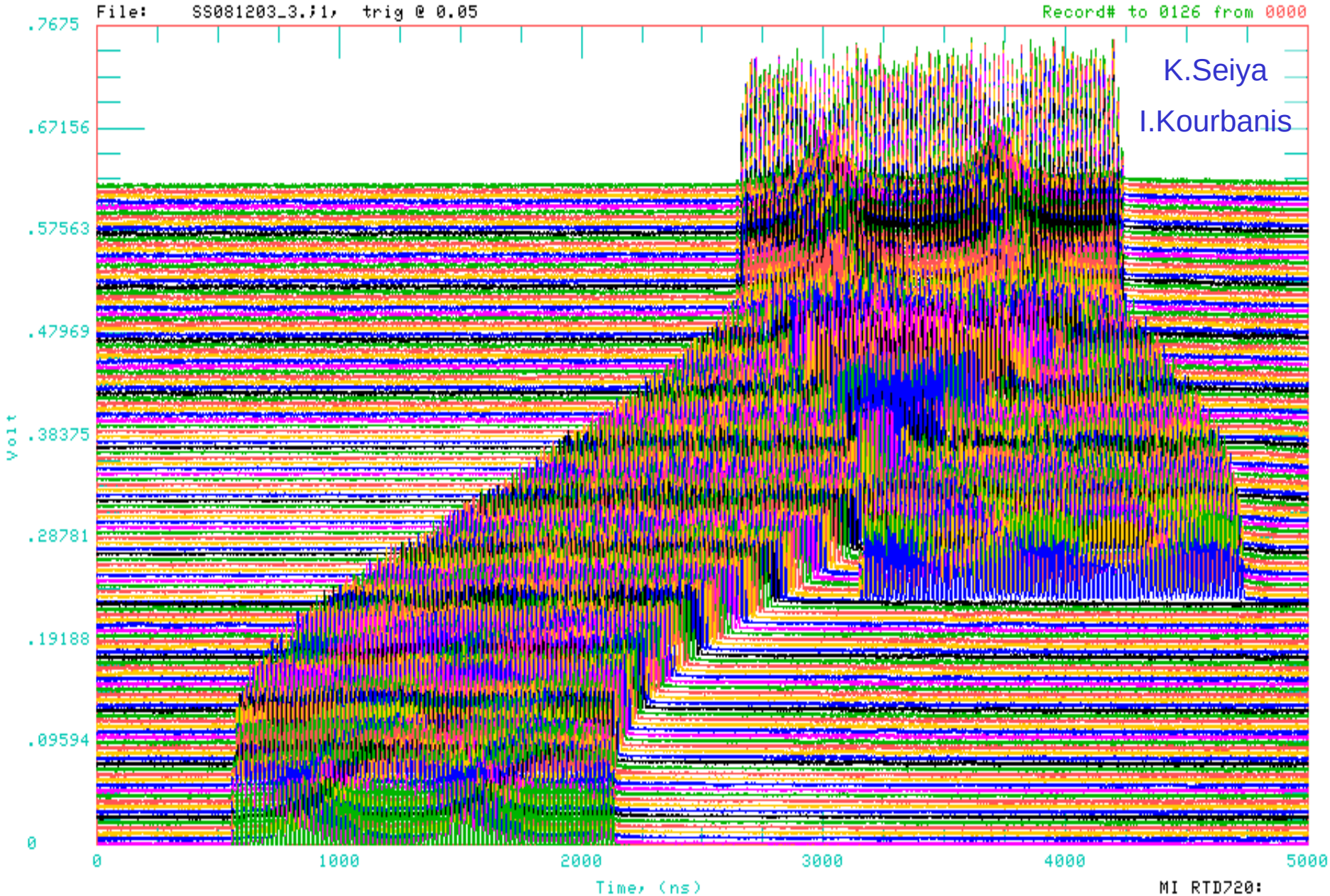
3. First Booster Batch slightly accelerated in MI with RF System A. Second Booster Batch accelerated in Booster

4. Second Booster Batch injected onto MI central orbit with RF system B

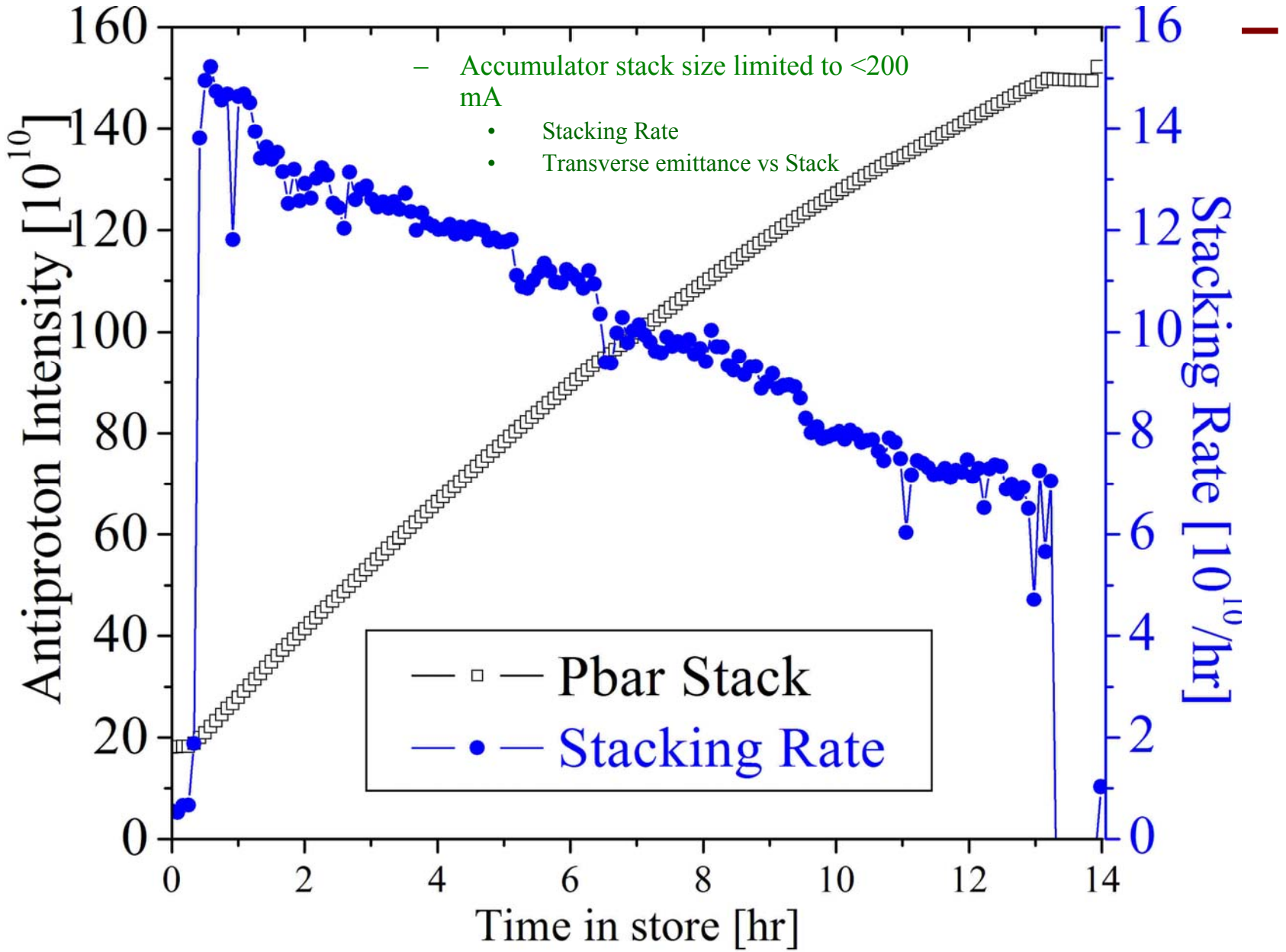
5. Second Booster Batch slightly decelerated in MI with RF System B

6. Wait till batches line up and snap on RF system C while turning of RF systems A & B

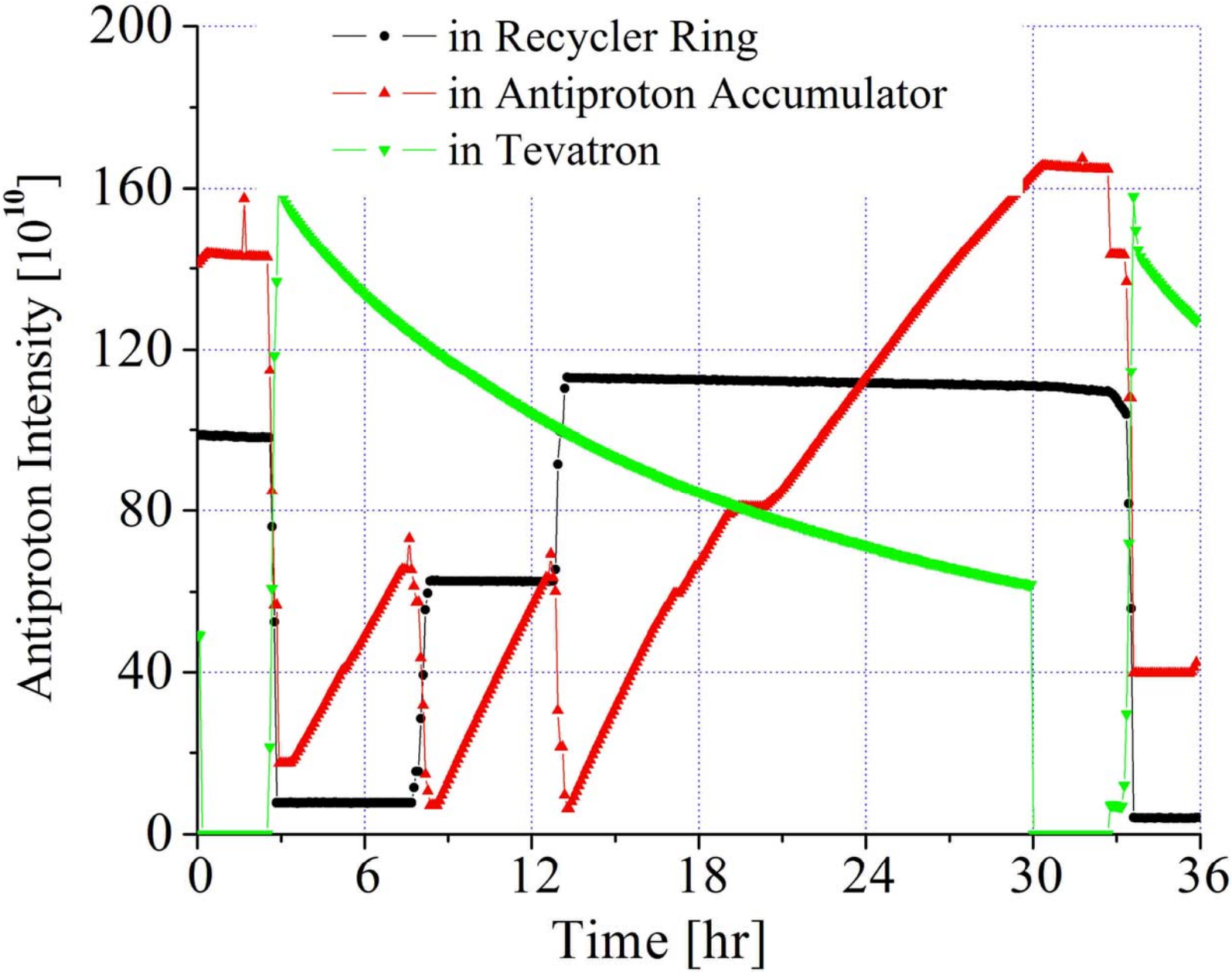
Slip Stacking (6-8)e12 p's in Main Injector



Antiproton Accumulator: Stacking Rate Falls



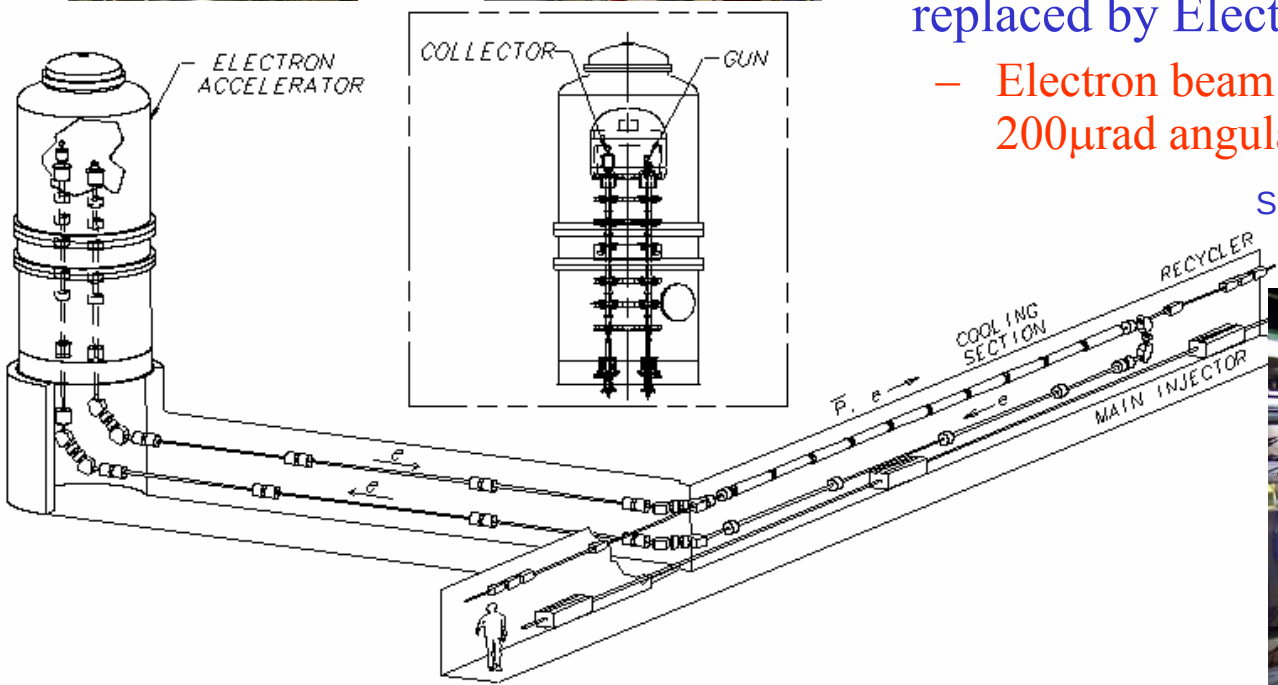
"Combined Source" Shots: (RR+AA) → Tevatron

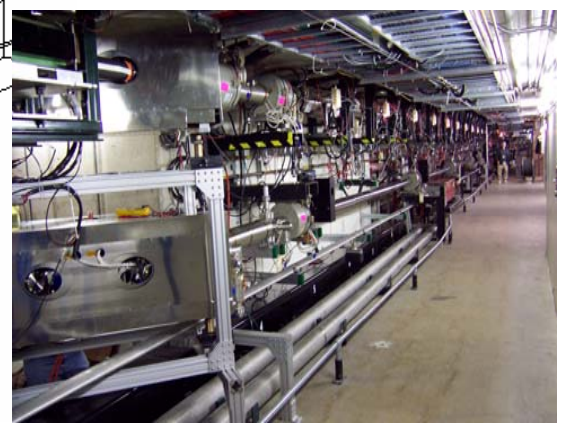


Recycler Electron Cooling

- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is being replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5A DC – 200μrad angular spread

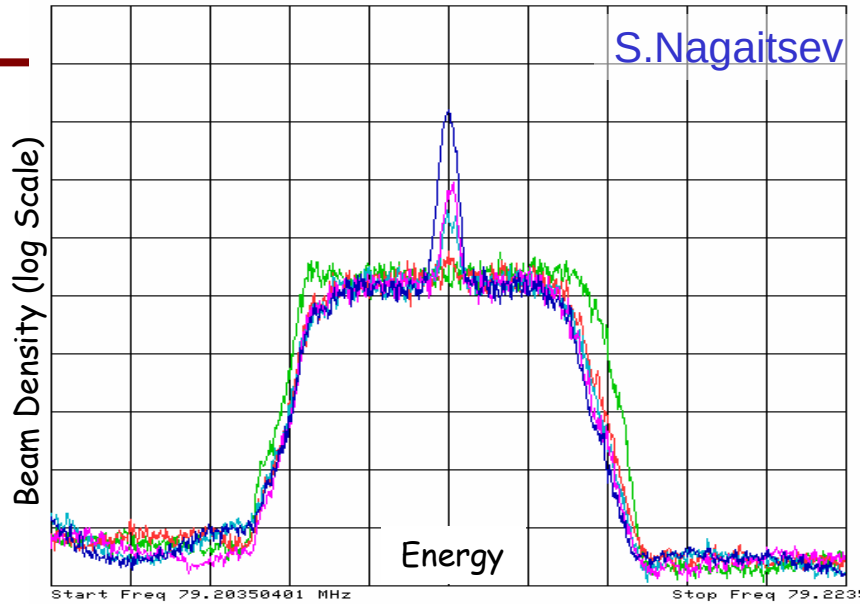
S.Nagaitsev, J.Leibfritz, A.Shemyakin

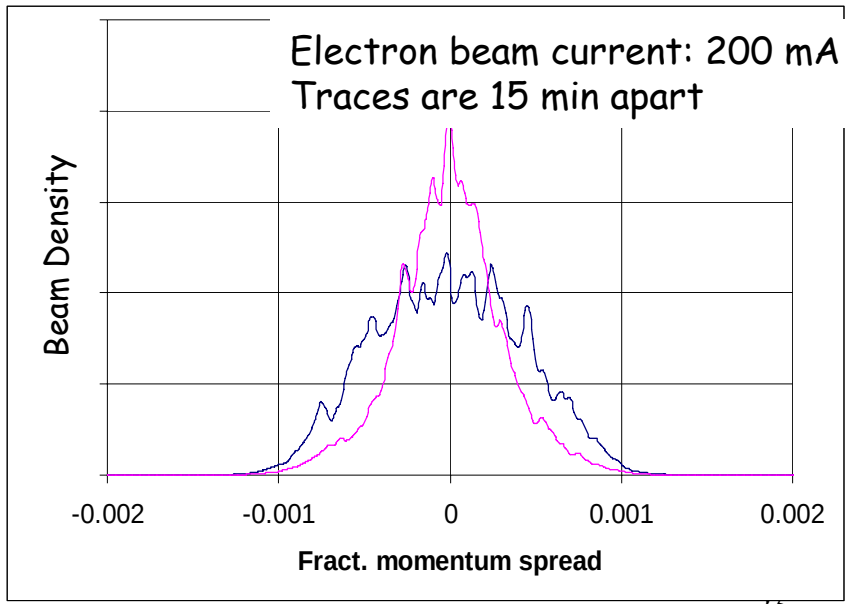




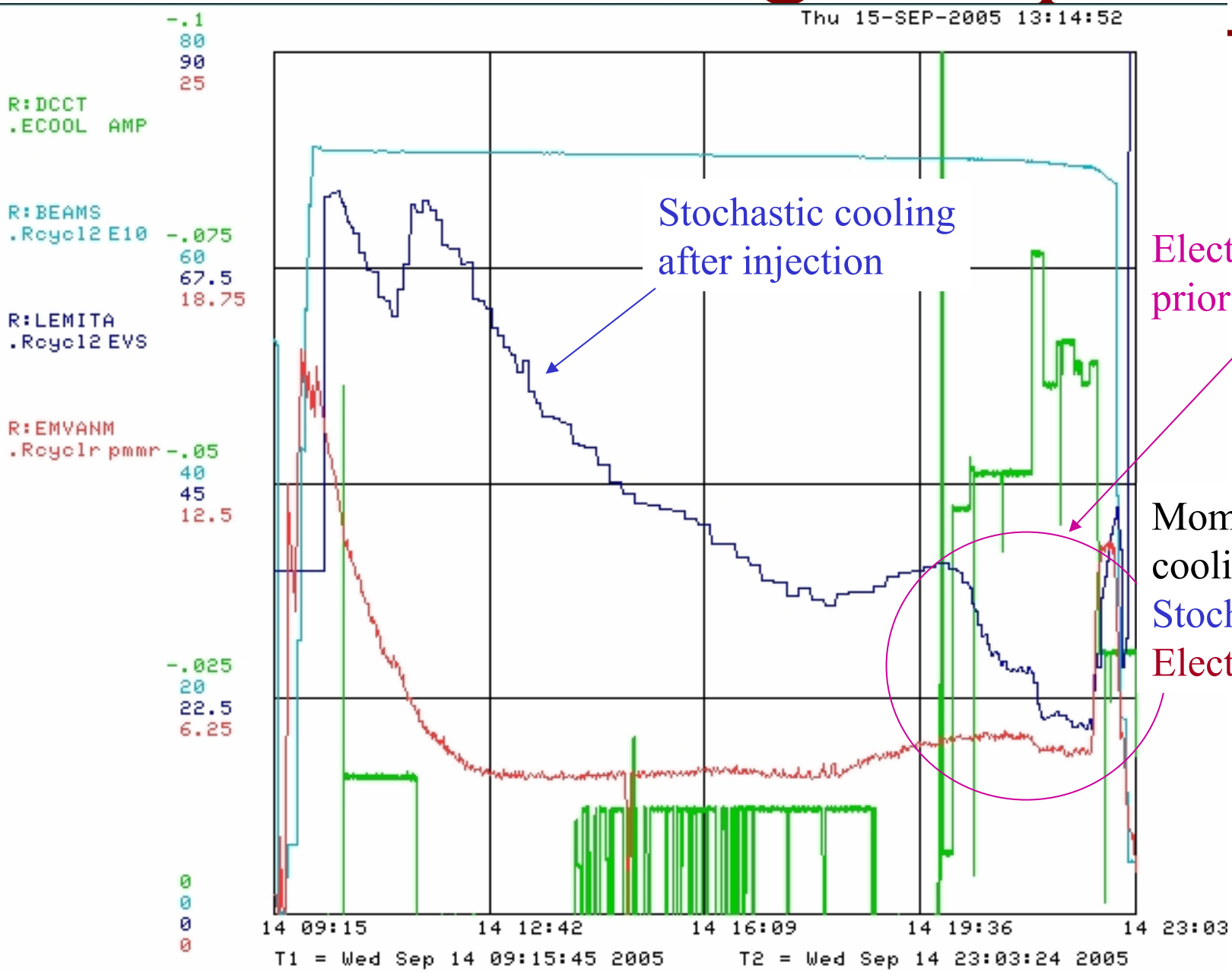
Electron Cooling Commissioning (July 05)

- Electron cooling commisioning
  - Electron cooling was demonstrated in July 2005 two months ahead of schedule.
  - By the end of August 2005, electron cooling was being used on every Tevatron shot
- Electron cooling rates
  - Drag rate: 20 MeV/hr for particles at 4 MeV
  - Cooling rate: 25 hr^{-1} for small amplitude particle
  - Can presently support final design goal of rapid transfers (30eV-sec every hour)
  - Have achieved 500 mA of electron beam which is the final design goal.





Electron Cooling in Operation

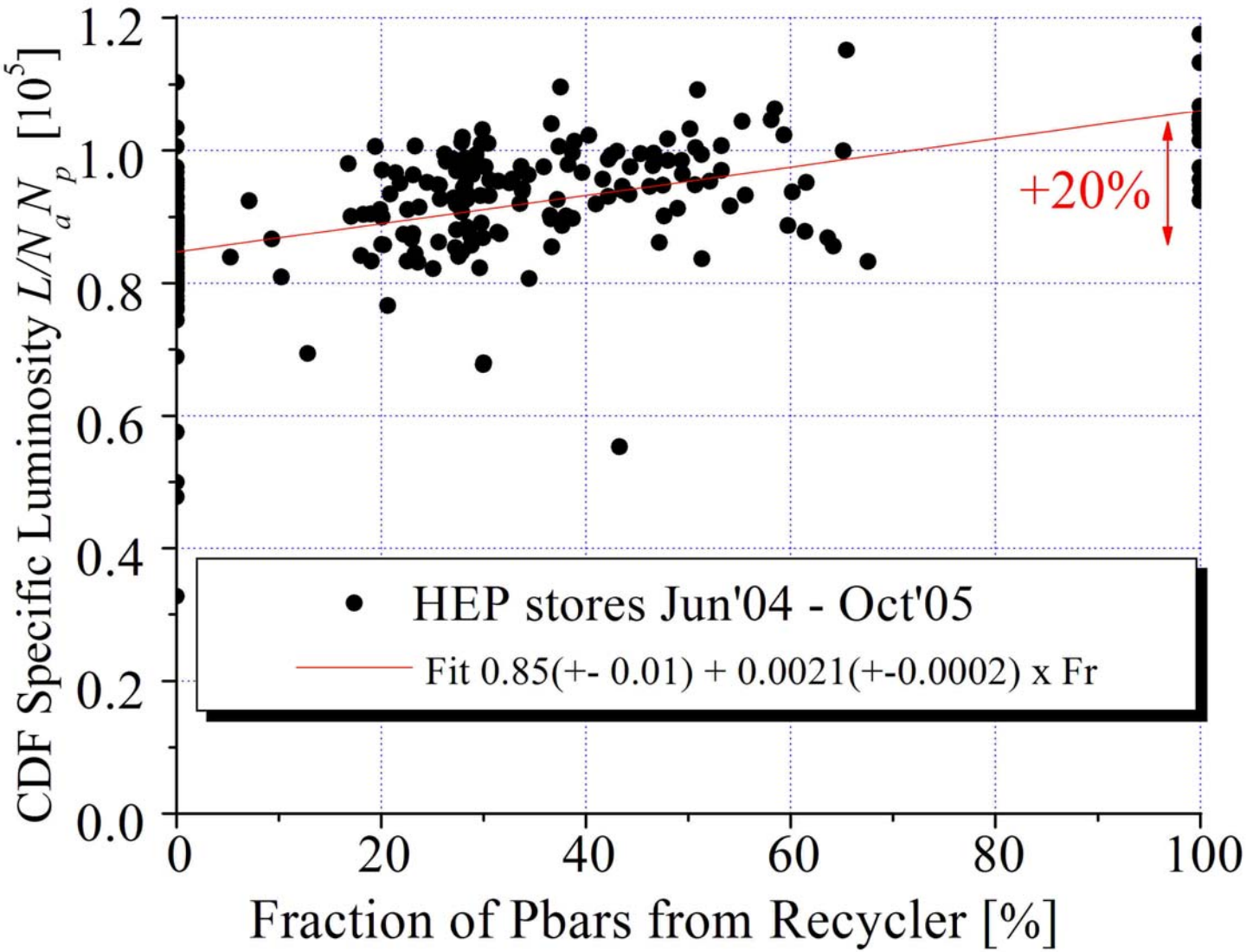


Momentum cooling times:

Stochastic ~3 hrs

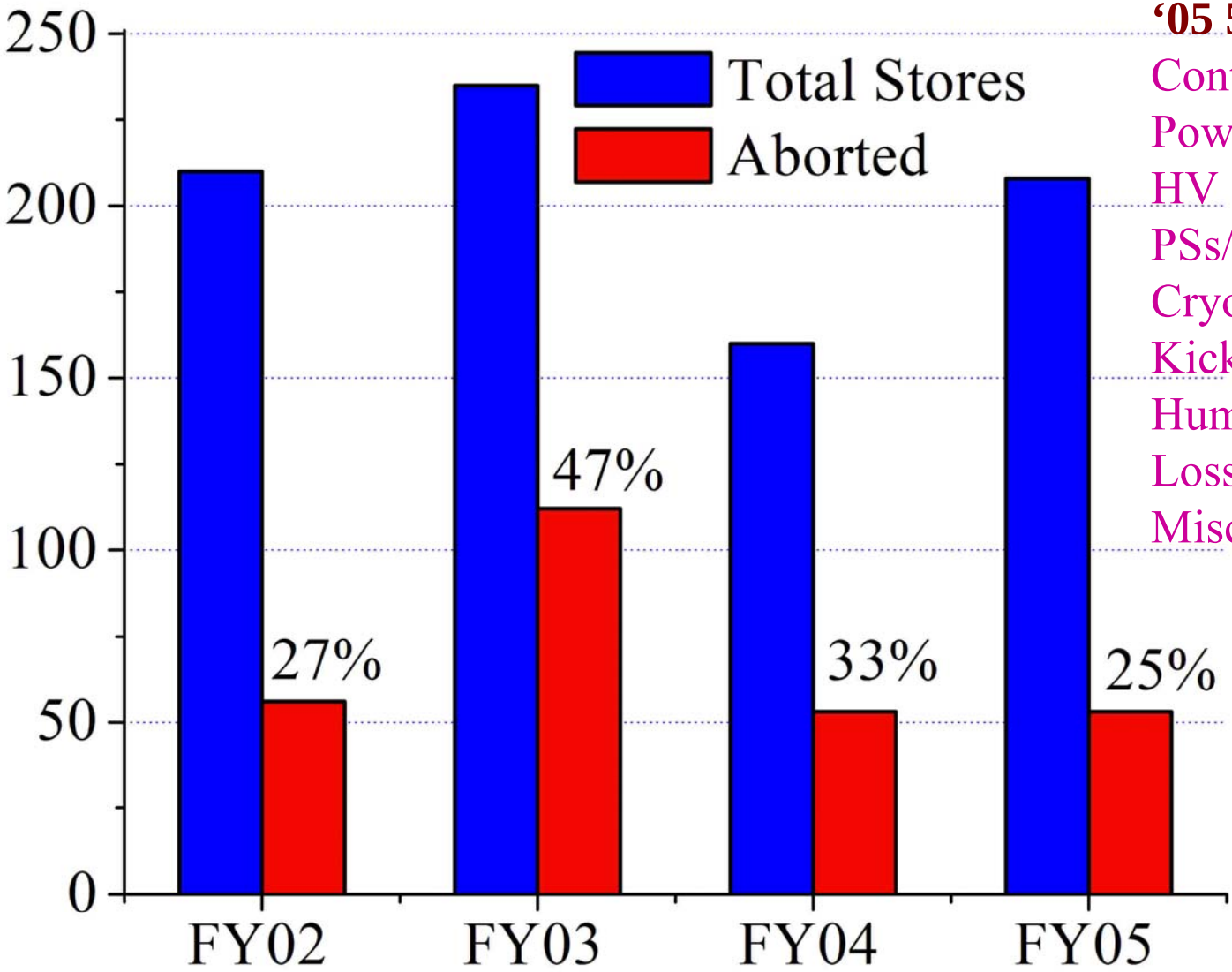
Electron <1 hr

Smaller Emittances from RR



– We're switching to "Recycler only" shots to gain ~10%

Store Endings (Unintentional)



'05 53 stores lost:

Controls	10
Power glitch	8
HV sparks	6
PSs/QPM	5
Cryo	4
Kicker Prefire	3
Human Error	3
Losses	3
Misc	11

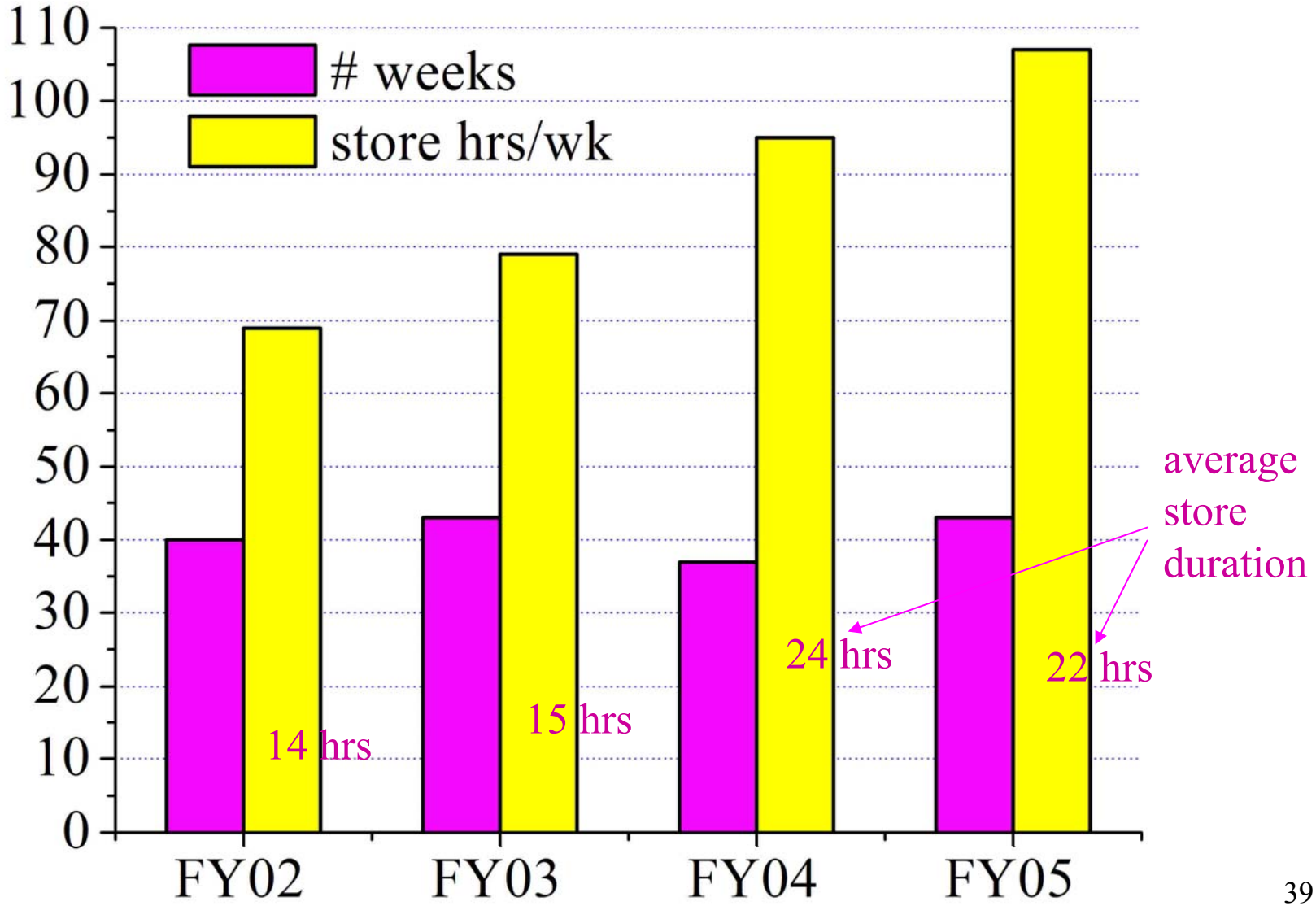
Greatly reduce since FY03:

QPMs

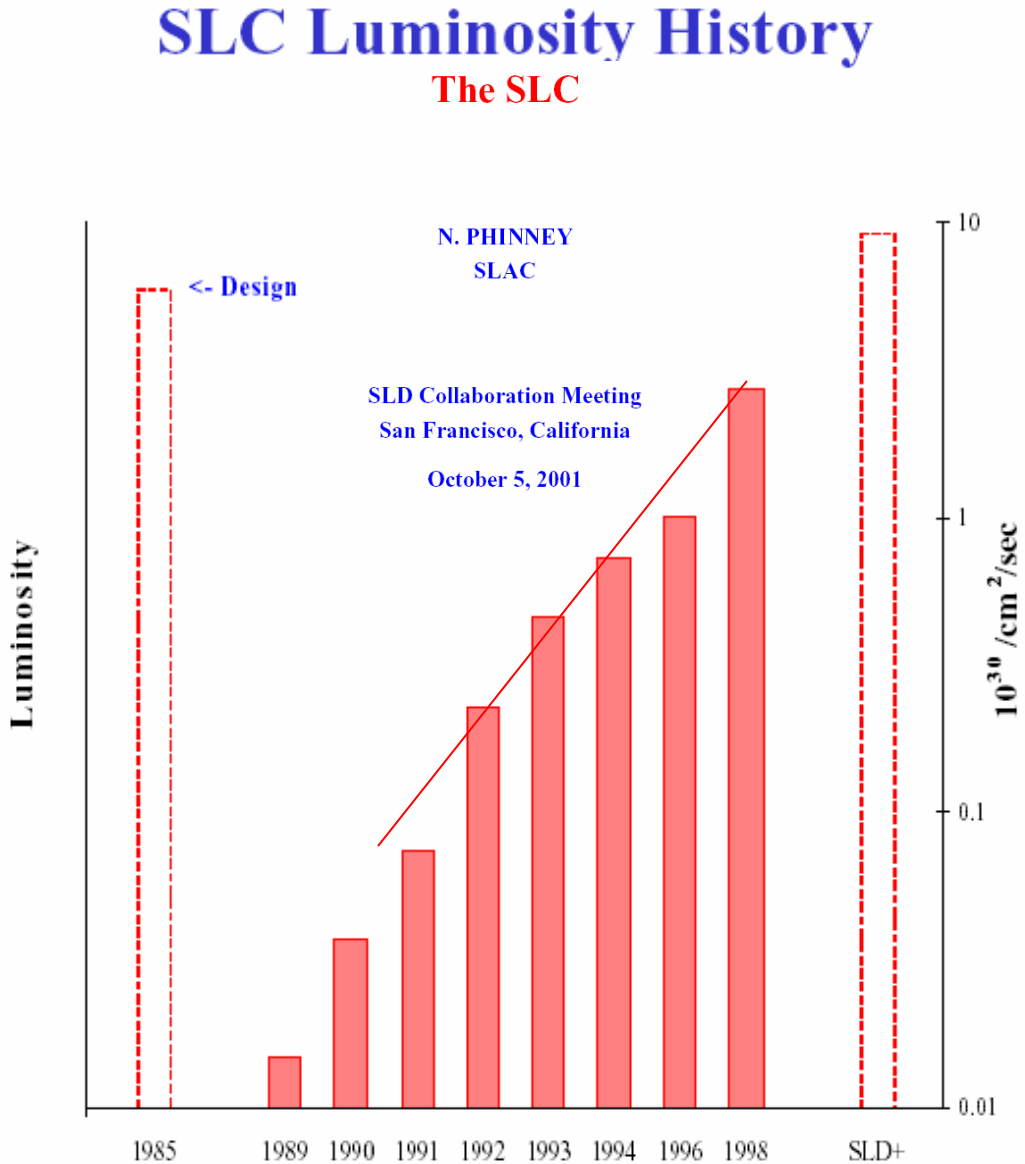
RF

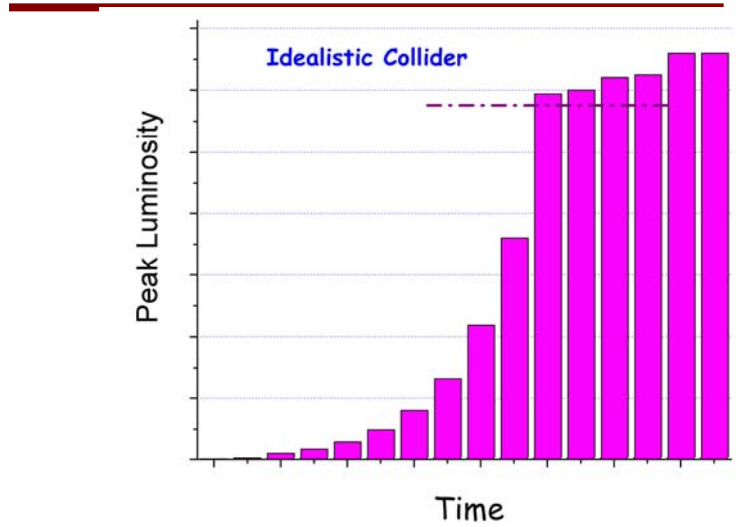
Cryo

Rigorous Work on Reliability



Luminosity Evolution - General



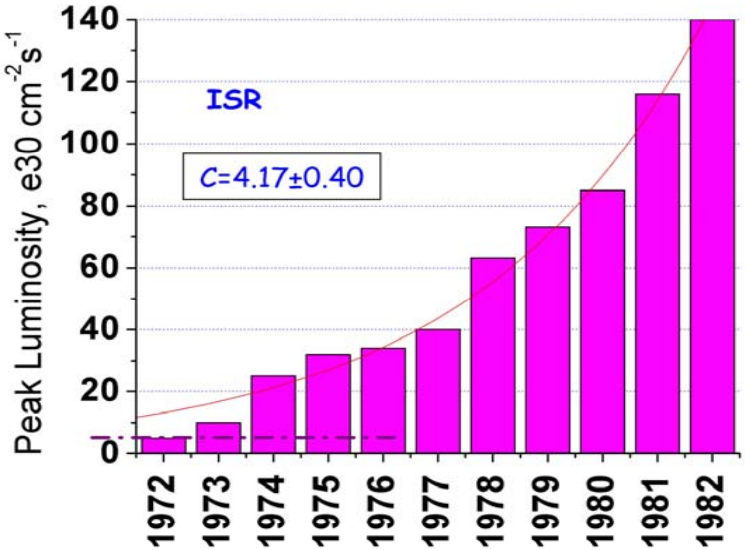


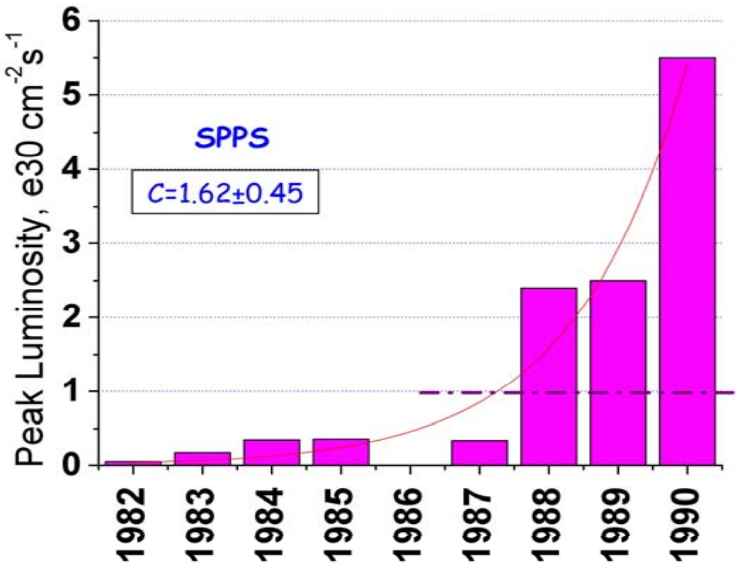
$L \sim \exp(T/C)$

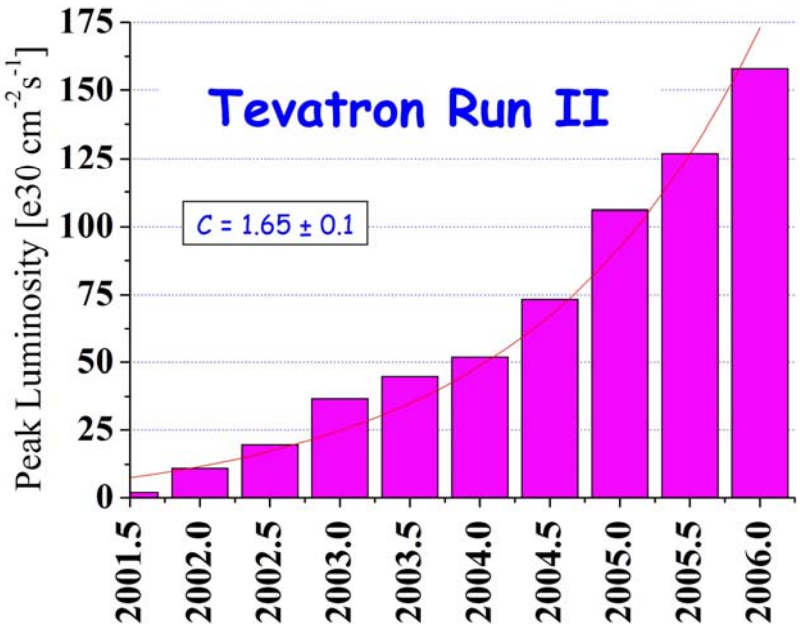
or $C \times P = T$, $P=\ln(L)$

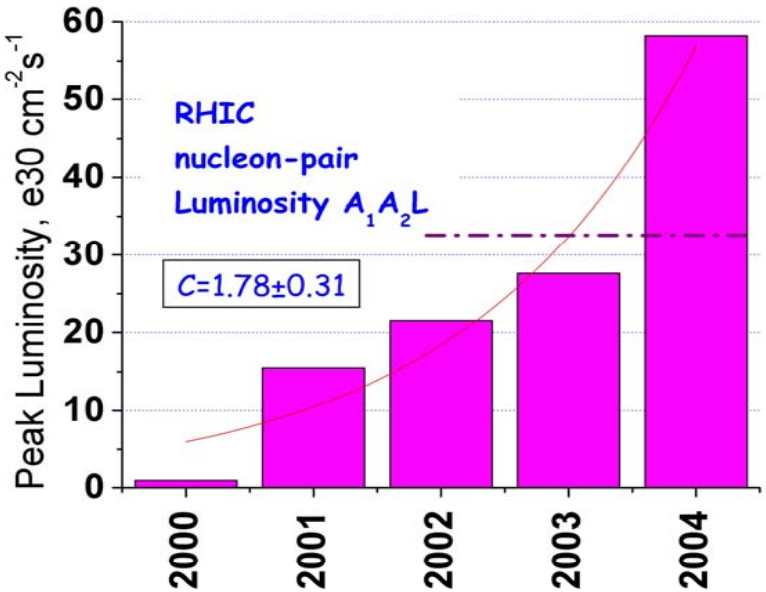
e.g., for SLC 1993-98
dT=5yrs, dP=ln(3/0.3)=2.3
C = 2.2 (years to gain *e*)

"*CPT-Theorem*" - Examples









Tevatron & Other Hadron Colliders

FNAL-Conf/04-126

	C*, average time** **e-*fold increase	*L, e30*	
Tev Run I	0.9 yr	25	
Tev Run II	1.7 yr	158	
SppS	1.6 yr	5.5	
RHIC	1.8 yr	58	A_1A_2L
HERA	3.0 yr	51	
ISR Run II	4.2 yr	140	1982

…so, Tevatron had / has an excellent growth

So, What's Ahead?

"Life is Merrier with Every Day!"

Maximize Luminosity Integrated By '09

Operate and upgrade Tevatron complex till start of LHC.

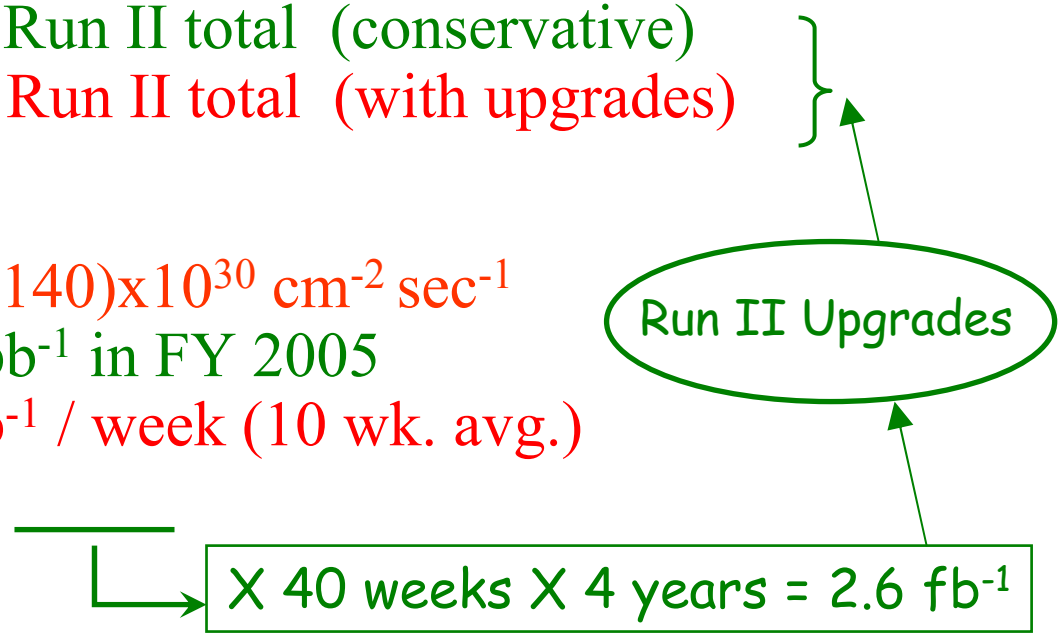
Collider Run II March 2001 $\Rightarrow$ 2009.

Integrated Luminosity at CDF and DZERO

- Delivered 1.3 fb^{-1} as of October 2005
- Plan for 4.1 fb^{-1} Run II total (conservative)
- Design 8.2 fb^{-1} Run II total (with upgrades)

Current performance

- Peak Luminosity (100-140)x10^{30} cm^{-2} sec^{-1}
- Integrated 600 pb^{-1} in FY 2005
- Integrating @ 16 pb^{-1} / week (10 wk. avg.)



Run II : Now vs 2009

980 GeV/beam, 36 x 36

Parameter	Now	FY09	
Initial Luminosity	110-140	270	e30 $cm^{-2}sec^{-1}$
Integrated Luminosity	16	28	pb^{-1}/wk
Total Int. Luminosity	1.3	4.8-5.4	fb^{-1}
Protons/bunch	235	300	e9
Antiprotons/bunch	35 - 50	75	e9
Proton emit. (95%, norm)	16	16	πmm-mr
Pbar emit. (95%, norm)	11	8	πmm-mr
Beta @ IP	0.28	0.28	meter
Hourglass factor	0.58	0.58	
Peak Pbar Production Rate	16.6	>20	e10/hr

Luminosity Upgrade Strategies

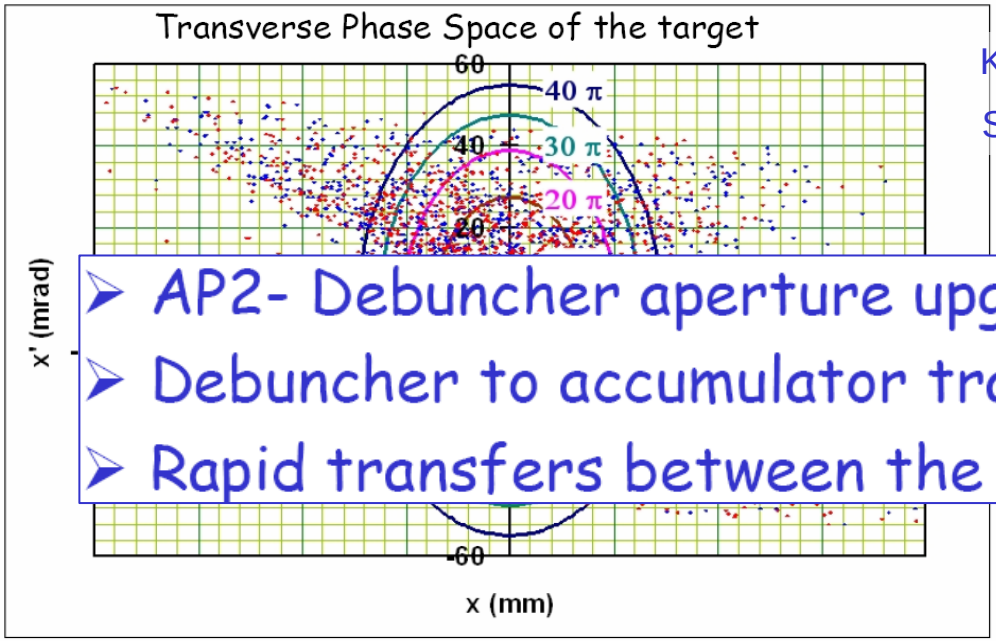
- Increase pbar production rate → more pbars at LB
  - + open apertures after target >20% in peak L
- Use antiprotons more efficiently
  - + Recycler only shots 10-15% in peak L
  - + improve (HV separation, Q') 5-10% in integral L
  - + 2.5 MHz acceleration in MI 4-7% in integral L
  - + recycling of Tevatron pbars 15-25% in peak L
- More protons at IP
  - + New working point near ½ 15-25% in peak L
  - + Beam-beam compensation TELs 4-8% in integral L
  - + MI 20-bunch coalescing with RF.b.b. 10-20% in peak L

TOTAL: ~ double peak luminosity, >+60 % in weekly luminosity int

Major Run II Pbar Source Upgrades

- Increase proton flux to antiproton target
  - Slip stacking in the Main Injector — in operation
  - Improved antiproton target — ongoing
- Improved Antiproton collection
  - Lithium lens upgrade — recently installed
  - AP2 transfer line and Debuncher acceptance — ongoing
- Antiproton stacking and cooling
  - Recycler Ring Stacking and Electron Cooling — in operation
  - Every 30 minutes transfer pbar stack from Accumulator to Recycler
  - Stack tail cooling upgrades in Accumulator

Antiproton Aperture



K.Gollwitzer

S.Werkema

- AP2- Debuncher aperture upgrade
- Debuncher to accumulator transfers
- Rapid transfers between the Accumulator and Recycler

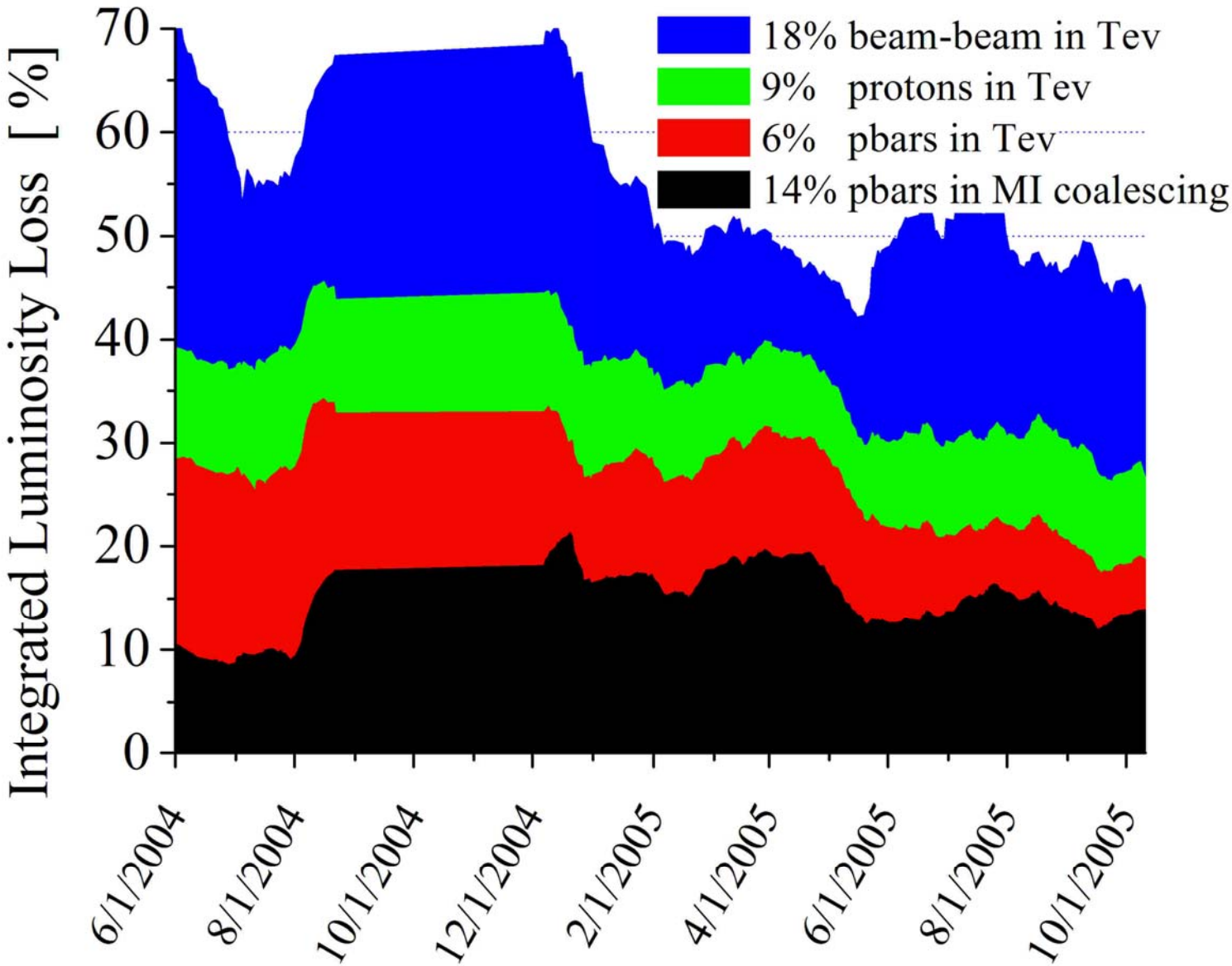
The measured aperture of the initial stages of the antiproton production chain is about 65% of the available physical aperture.

An aggressive beam-based alignment program is under development to bring the measured aperture to the physical aperture.

- Would increase the stacking rate by over a factor of 2
- The final design goal is to achieve 77% of the physical aperture which will increase in stacking rate by 40%

The goal for this year is to increase the aperture for each plane from 65% to 72% of the available physical aperture which would result in a 20% increase in antiproton production rate

Sources of Luminosity Loss



Beam-Beam Losses: Projections for FY09

	Mar-Apr'05	*IF RUN "AS NOW"!*	
	Now	3xN_a	3xN_a 1.4xEmm
P at 150	4.4% ± 2.8	13.2	13.2
A at 150	3.9% ± 2.2	3.9	7.8
P ramp	3.4% ± 0.9	8.2	8.2
A ramp	4.7% ± 1.2	4.7	8.4
P squeeze	1.0% ± 0.4	3.0	3.0
A squeeze	1.5% ± 0.5	1.5	2.0
Total before LB	*18.9% ± 3.9*	*34.5*	*42.6*
Tau_p at LB	160 hr ± 60	~60	~100
Tau_a at LB	160 hr ± 60	~160	~80
Total in Tau_L	*10% ± 5*	*~13%*	*~13%*
Total Int-L	***28% ± 7***	***44%***	***50%***

Beam-Beam Tune Shifts

$$\xi = 2\frac{N_p r_p}{4\pi\varepsilon_p}$$

head-on tune shift, two IPs, now with N_p=240e9 and 95% emittance 15π

total max head-on tuneshift is 0.025 for pbars, 0.007 for protons

tune shift for separated beams is smaller:

$$\Delta\nu = \sum_i \frac{\beta_i N_p r_p}{2\pi\gamma d_i^2} = \sum_i \frac{2\xi}{(d_i/\sigma_i)^2}$$

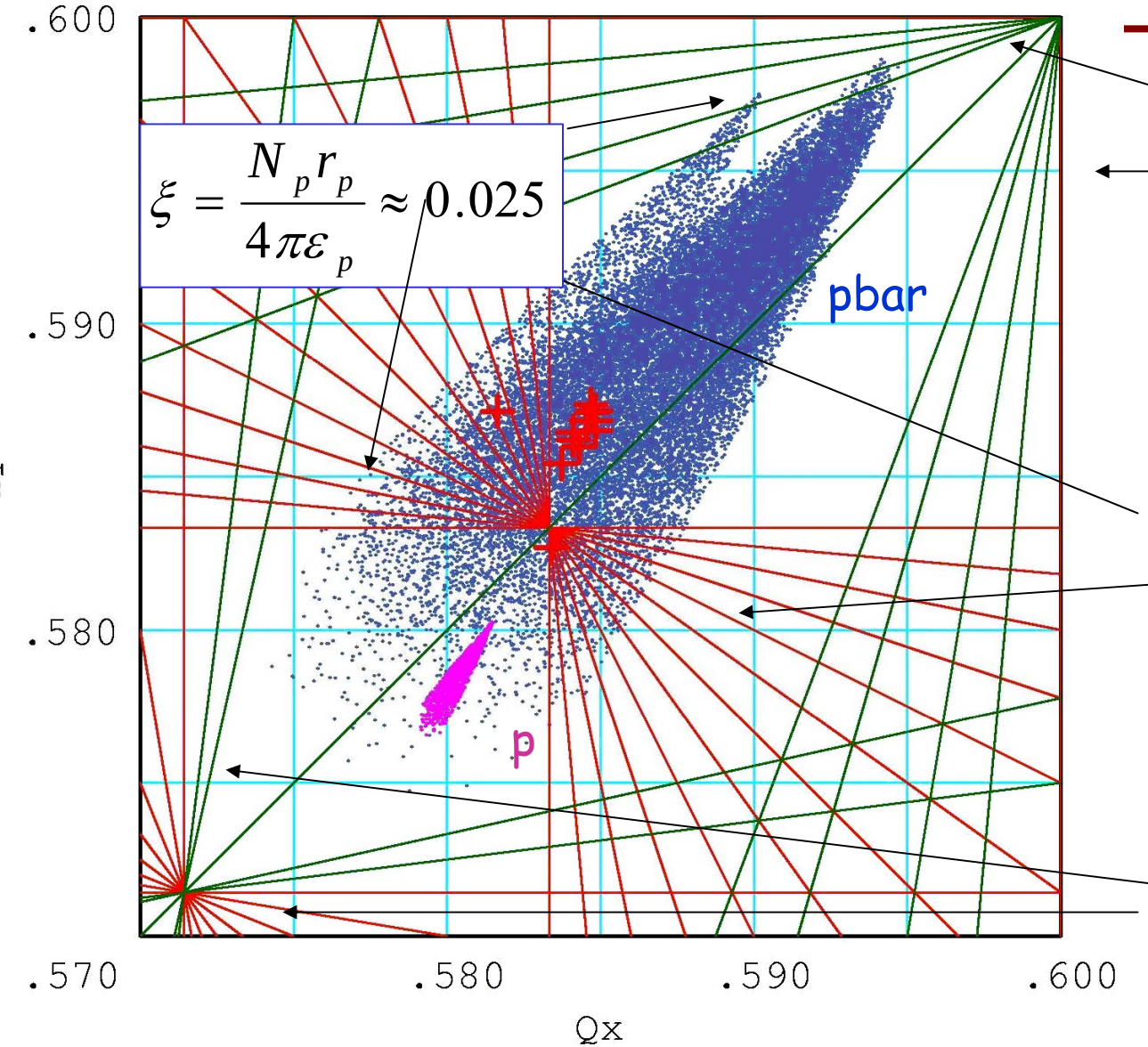
but: a) always present, Δν=0.002-0.005

b) MANY near-misses i = 70

c) different bunch-by-bunch

d) HV separator limited: γd² scales as V² / γ

Situation at LB Now: Confined Beams



$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p} \approx 0.025$$

5th order resonances:
Q=3/5=0.600 -
EMITTANCE BLOWUP

12th order resonances:
Q=7/12=0.583 -
Bad lifetime

7th order resonances:
Q=4/7=0.571 -
HIGH LOSSES

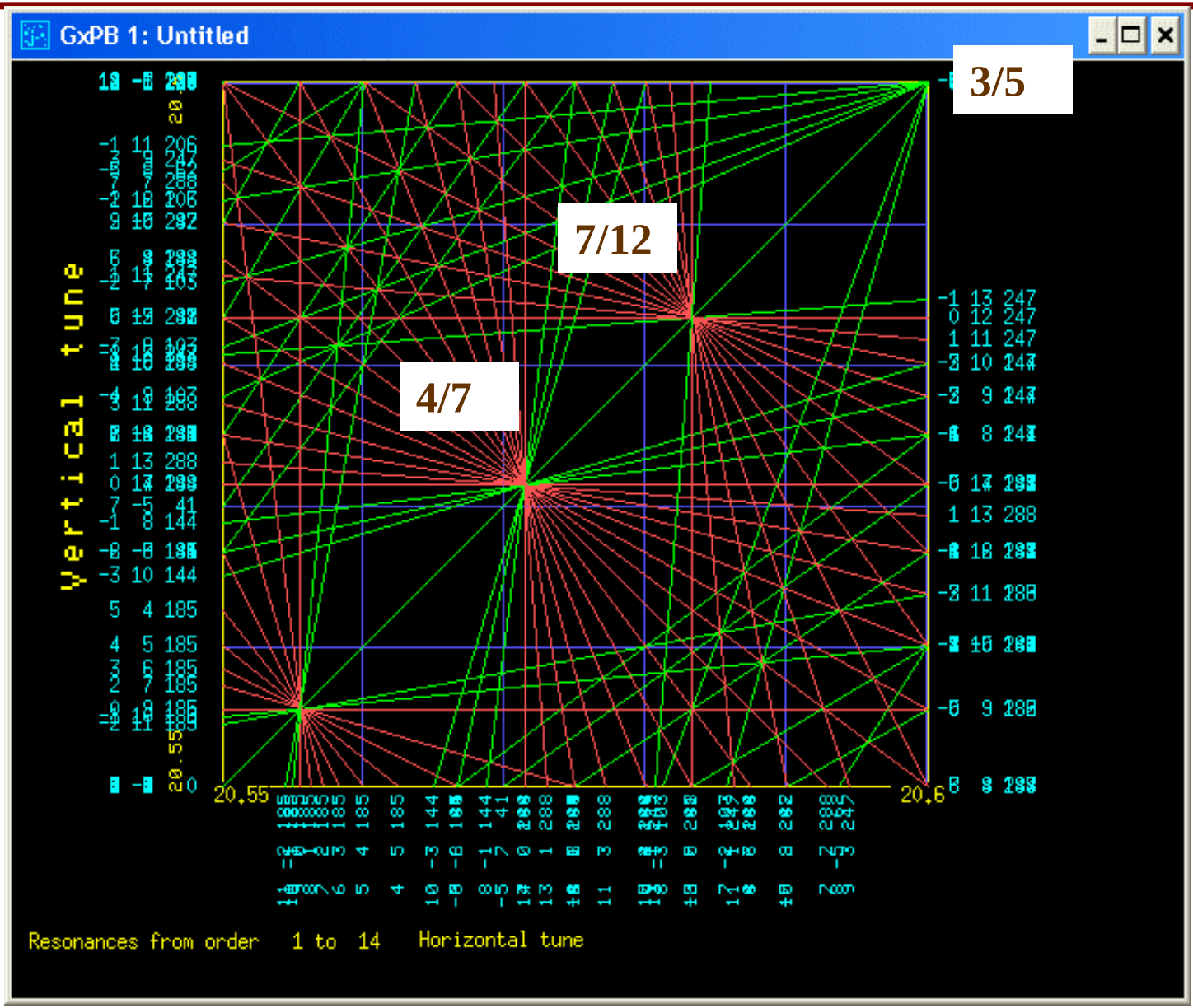
Beam-Beam Tune Shifts

$$\xi = \frac{3 N_p r_p}{2\pi \varepsilon_p^{95\%}} \times N_{IP}$$

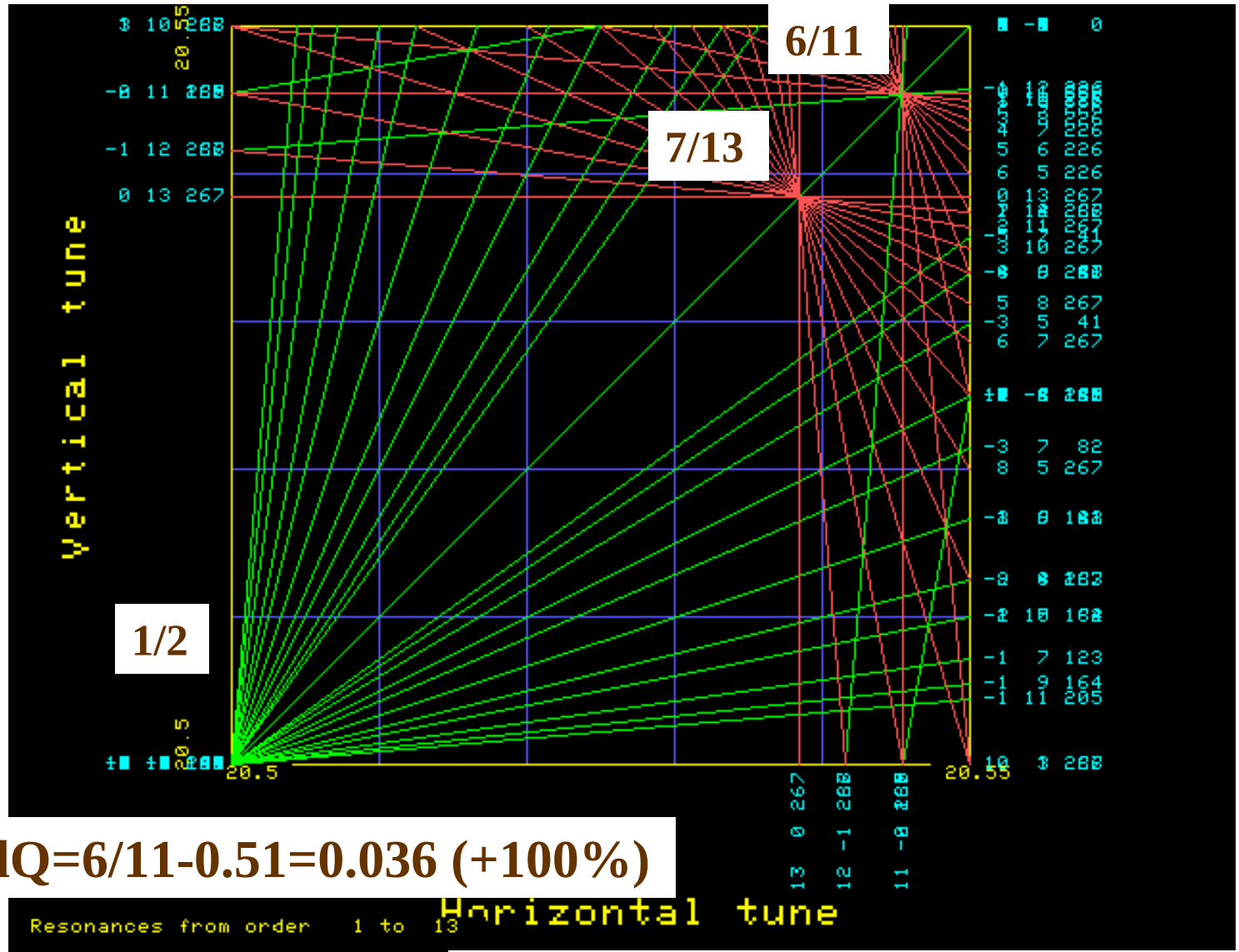
• Tevatron	a/p	+0.025/+0.007
• RHIC	p/p	-0.014
• HERA	p/e-	+0.0014/0.045
• KEK-B	e+/e-	+0.113/0.072
• PEP-II	e+/e-	+0.064/0.045
• DAFNE	e+/e-	+0.055
• LHC	p/p	-0.010

ca 2004

Tune Space Now: 3/5-7/12=0.017



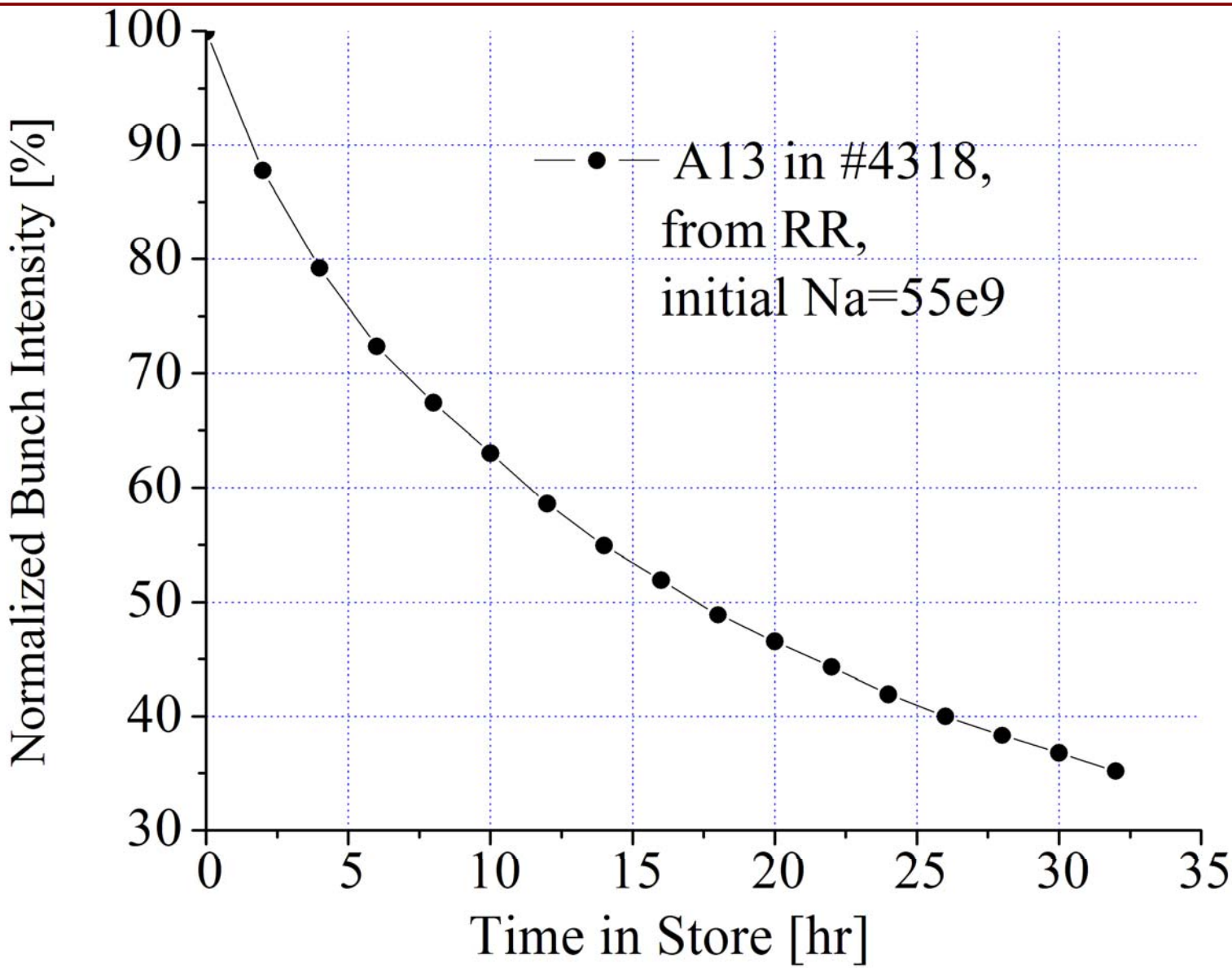
New WP: dQ=7/13-0.51=0.0028 (+50%)



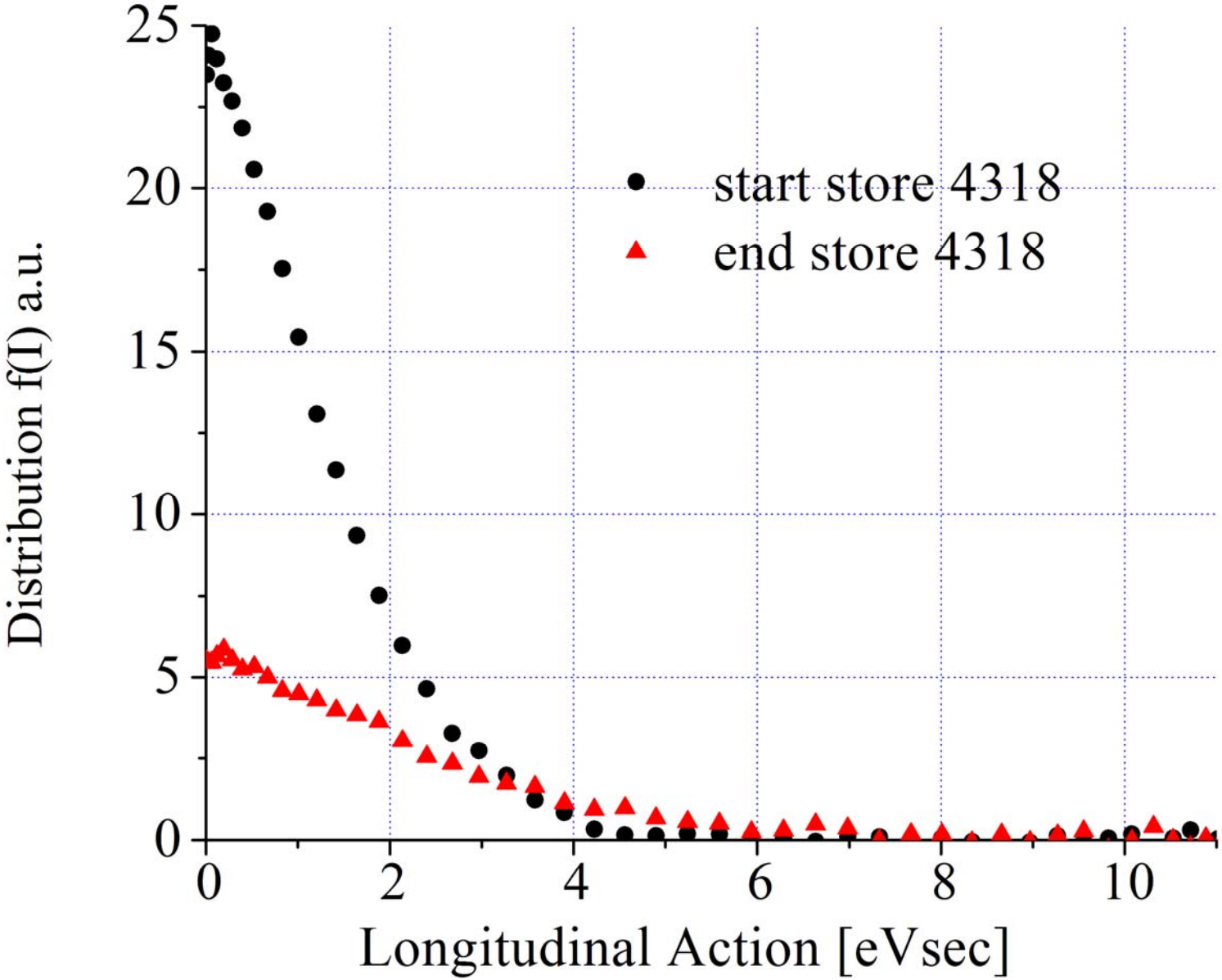
Or even dQ=6/11-0.51=0.036 (+100%)

… just get more protons +20…+40?%

Pbars in the Tevatron: 35-50 % Leftover



Pbars in the Tevatron: Evolution



Recycling: Possible Losses & Gains

Store Length	20 hrs	30 hrs
Left in Tev	46% x	37% x
Deceler Eff	-(5-8)%	-(7-10)%
Tev→MI Eff	-(4-6)%	-(4-6)%
MI Deceler Eff	-(5-10)%	-(5-10)%
MI→RR Eff	-(5-15)%	-(10-20)%
Trsf Time 2/3 hr	-(1-3)%	-(2-4)%
Gain in RR Na	+(30-37)%	+(22-27)%
Gain in L_peak	+(24-30)%	+(18-22)%
Gain in L_integr	+(19-24)%	+(14-18)%

The End!

Backup Slides